AN

INTRODUCTION

TO THE

True ASTRONOMY:

OR,

Aſtronomical Lectures,

Read in the

Aſtronomical School

OF THE

UNIVERSITY of *OXFORD.*

By *JOHN KEILL*, M. D. Fellow of the *Royal-Society*, and Profeſſor of *Aſtronomy* in that Univerſity.

The Works of the Lord are great, ſought out of all them that have Pleaſure therein, Pſal. CXI. v. 2.

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TO

His Grace *JAMES* Duke

OF

CHANDOS.

May it pleaſe your Grace,

AMong all the Mathematical Sciences which have been continually improved, and are daily improving in the World, the firſt Place has, as it were, by general Conſent, been always given to Aſtronomy. *And ſuch has been either the good Fortune of the Science, or the Virtue of Mankind, that the greateſt and moſt eminent Perſons in all Ages and Nations, have been Patrons and Encouragers of this Study above all others.*

May it please your Grace, therefore to take this Book into your Protection, since whatever may be wanting, either in the Work or the Author, to recommend it to your Favour, will abundantly be supplied by the Dignity of the Subject.

For to whom can I so properly send a Treatise of the Stars and Heavenly Motions, as to a faithful and zealous Servant of that Heavenly King, who knoweth the Number of the Stars, and calleth them by their Names. *So remarkable is your Grace's Zeal for the Service and Honour of God, that you took particular Care to adorn* his House *before you would lay the Foundation of your* own. *Nor did your Care extend only to the Orna-*

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ments of the Temple, but likewise, and more especially to the Decency of the Worship: You call'd Musick in to excite Devotion; Musick being the Delight and Employment of the Heavenly Choir.

You, My Lord, are the publick and standing Mark of all Mens Admiration, the beautiful Patern which all desire to imitate, tho' few can hope to equal. In publick Affairs what Statesman more able? In domestical Management, what private Man more expert? In the constant stating and exact keeping of Accompts, no Body more Provident, no Body more Frugal. In Expences, no Body more Liberal: In Largesses, no Body so Magnificent.

So great is your Affection to Learning and the Learned, that while you make yourself Master of every Art, you give Matter and Encouragement to every Artist. To the particular Science which is the Subject of this Book, your Grace is so Eminent, so Benificent a Patron, that in the stately and beautiful Structure of Cannons, *Astronomers will find every thing for the Improvement of their Knowledge; Instruments worthy of the Science, and an Observatory worthy of its Lord.*

The Book I now present is a Translation of those Astronomical Lectures, which were honoured with your Grace's Name at their first Publication, in the Language they were read in at the University of Oxford. *The*

Version

Verſion was made at the Requeſt and for the Service of the fair Sex, and particularly for the Service of the great Ornament of her Sex the Dutcheſs of Chandos. *It is no Flattery to the Ladies to ſay that ſuch of them as delight in Arts and Sciences, as to Quickneſs of Perception and Delicacy of Taſte, are equal, if not ſuperior to Men; and it is no Affront to the moſt refined of either Sex to ſay, there is not a finer Genius than my Lady Dutcheſs.*

May every Star in Heaven ſhed its kindeſt Influence on both your Heads. And may you long continue to enjoy that Affluence, which, like the Rays of the Sun, ſcatters Light and Warmth to all round you.

This,

This, my Lord, is à general Wish, because it is for the General Good of Mankind, particularly of him who is with the deepest Sense of Gratitude,

Your Graces

most faithful

and most humble Servant,

JOHN KEILL.

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PREFACE.

AMONG all the Gifts and Benefits the most bountiful God has most plentifully bestowed on Mankind, those are in the first place Valuable, which consist in the Improvements of the Mind by Arts and Sciences. And as among the Sciences there are none which *Astronomy* comes behind upon the Account of its Antiquity, and the Pleasure that attends the Study of it; so it will yield to none of them on the account of its usefulness, and the Advantages it affords to Human Life. By it we discover the wonderful Harmony of Nature, wherewith the Frame and Structure of all Created Beings are linkt and knit together, to constitute the great Machine of the Universe. *Astronomy* teaches us to observe and discover the Motions of the Heavenly Bodies, and it weighs and considers the Force and Vigor by which they circulate in their Orbs. It is a Science which the greatest Heroes from the beginning of the World have taken Pleasure to Study and improve; so that it was always esteemed as a Science fit for Kings and Emperors to employ themselves in. On which account the *Chaldean* Wisemen and Philosophers were always reverenced and favoured by the Antient Kings, who

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thought it absurd, that any should Govern the World, who knew not what the World was.

THE Excellency of this Science appears from this, that their is no Knowledge which is attained by the Light of Nature, that gives us truer and juster Notions of the Supreme and Almighty God the Maker of both Heaven and Earth, than it does. None furnishes us with stronger Arguments by which his Existence is demonstrated; nothing shews more his Power and Wisdom, than the Contemplation of the Stars and their Motions. That Prophet as well as King, the Holy *David*, tells us, that *The Heavens declare the Glory of God, and the Firmament sheweth his handy Work.* And again, *The Heavens declare his righteousness, and all the People have seen his Glory.*

MARCUS Tullius Cicero who was guided only by the Light of his own Reason, had the same Sentiments. *Nothing says he, is more evident, nothing plainer when we look up to the Heavens, and contemplate the Bodies there, than that there is a Deity of most Excellent Wisdom who Governs them.* What is there that more ravishes the Mind of Man into an Admiration, Reverence and Love of God, than so many and so great Bodies endowed with Heavenly Light, most beautiful to the Eye, and when contemplated, most delightful to the Understanding. Their mutual intercourses, most regular Motions, their certain and determined Circulations, and their Returns and Periods setled by a Divine Law, in an admirable Harmony, make manifest to us the immense Power, Wisdom and Providence of their Maker; which when we consider we must necessarily acknowledge, Reverence and Celebrate the Author and Contriver of all these things.

BESIDES *Astronomy* with its Sublime Speculations, about so many and so large Bodies, and at such immense distances, does wonderfully please and recreate the Mind.

ASTRONOMY for the certainty and evidence of its Demonstrations, is not Inferiour to *Geometry*;

try; its ufefulnefs is manifold, and the Amplitude of its *Subject* is fo large that it comprehends nothing lefs than the World it felf. For as among all the liberal Sciences there are none that contemplates Objects more in Number, greater in Quantity, or at longer diftances from us than *Aftronomy*; fo likewife there are none in which there ftill remains fewer difficulties to be explained, Objections to be anfwered, or Scruples to be removed, than there are in *Aftronomy*; and no Science has yet attained fo great a degree of Perfection as it has.

IN moft of the other Arts there are feveral Inextricable Labyrinths; many ftrange Objections are raifed, and unanfwerable Arguments which do fo confound the Mind, that like thick Clouds, they ftop all further Profpect and difcovery. But the Motions of the Heavenly Bodies are now certainly known, and their caufes demonftrated, and the reafon of all the *Phænomena* of the Heavens are exactly underftood.

THE fmalleft Stars we can fee, tho' they be at an unmeafurable diftance from us, yet have their Longitudes and Latitudes exactly determined, their proper places fettled and are all reduced into Catalogues; tho' at the fame time the Science of *Geography*, or a Defcription of our own Habitation, is fo imperfect, that we have an exact Determination of the Longitudes and Latitudes of but a very few Places; there ftill remaining many *Unknown Lands* and Countries, that have not as yet been difcovered: And there are now great and far extended *Continents*, of which we fcarcely know any thing befides their Coafts and Shoars. And what is ftill more ftrange, in our little Provinces and Counties which we daily Travel over, their are many Towns and Cities whofe Pofitions are ftill uncertain; as is plain from the many *Geographical* Maps of them, which contradict each other.

THE *Aftronomers* foretel, for many Ages to come, the Eclipfes of both Sun and Moon, their Quantities and Durations: The Conjunctions,

Oppositions and mutual Aspects of the Planets, and what will be the distances of all the Stars from the Pole at any time: Whereas there is no Man so well skilled in *Meteorology*, as can certainly foretel what will be the State and condition of our Atmosphere for the very next Day, and yet it reaches but a few Miles from us: we are unable to judge whither we shall have fair Weather or foul, calm or stormy, or even so much as to foresee from what Point the Wind will blow. And this is no wonder, since the causes from whence these Effects arise are unsearchable.

NO *Philosopher* has ever yet discovered the Figures of the small parts of Matter, or the Texture, Intervals, Form and Composition of the parts of the most common Plant. Nor has any Physician yet found out the reason of the Virtues and Operations by which their Medicines affect Human Bodies. And even in all Animated and Vegetable Bodies, the Fountain and first Principle of Life and Action is unsearchable, and looks like a Mystery much beyond the reach of our Understanding, which Knowledge perhaps in this Life is never to be attained. But *Astronomers* in their proper Science meet with no such difficulties, they contemplate not the Natures, but the Motions of the Celestial Bodies, and they clearly account for the Phænomena or Appearances that arise from thence; they not only determine what sort of Motion the Planets have, and in how large a compass they circulate; but they likewise shew us the crooked Tracts in the immense Regions of Space which the wandering Comets take; they can give us the *Geometrical* Properties of their Orbits, and the Laws which they observe in describing them. The *Astronomers* are not ignorant where and when the Planets are at their furthest distance from the Sun, and participate the least of his heat and light; from whence they return, and are constantly quickned in their Motions by the Sun, who

draws them towards himſelf, 'till they come to thoſe parts of Space, where they make their neareſt approach to him, enjoy moſt of his heat and light, and are actuated by the greateſt force of their own Gravity.

MOST of the Diſcoveries we have related were known to the *Aſtronomers* of former Ages. But our Times, and this our Country of *Britain*, have had the happineſs to produce a *Genius* of a Divine Nature and extraordinary Qualities; I mean the Great Sir *ISAAC NEWTON*, who, beſides his innumerable other wonderful Inventions, has diſcovered the Fountain and Spring of all the Celeſtial Motions, and the Great Law which is Univerſally diffuſed thro' the whole Syſtem of Nature, which the Almighty and Wiſe Creator has commanded all Bodies to obſerve, *viz.* That every Particle of Matter attracts each other in a reciprocal duplicate Proportion of its diſtance.

THIS Law is, as it were, the Cement of Nature, and the Principle of Union, by which all things remain in their proper State and order; it detains not only the Planets, but the Comets within their due bounds, and hinders them from making excurſions into the immenſe Regions of Space; which they would do if they were only actuated by a Motion once implanted in them, which naturally they would always preſerve, according to the Principal Law of Motion.

WE are obliged to the ſame Gentleman for the diſcovery of the Law that regulates all the Heavenly Motions, ſetts bounds to the Planets Orbs, determines their greateſt Excurſions from the Sun, and their neareſt approaches to him. To this Sublime Genius we owe, that now we know the cauſe why ſuch a conſtant and regular Proportion is obſerved by both Primary and Secundary Planets in their Circulations round their Central Bodies, in comparing their diſtances with their Periods; and why all the Celeſtial Motions are ſtill continued in ſuch a wonderful regularity,

Harmony and order. The ſame incomparable Perſon having a compleat Knowledge of the Laws of Nature and Motion, has from them furniſhed us with a new Theory of the Moon, which accurately anſwers all her Inequalities, and accounts for them by the Laws of Gravity and Mechaniſm; ſo that now the Moon's place, computed by the Rules of this New Theory, does not ſenſibly differ at any time from what it is obſerved to obtain in the Heavens, which does exceed the hopes and Expectations of our *Aſtronomers*; ſo that we have now a Proſpect of improving our Navigation, by finding from Obſervations of the Moon, the Longitude of a Ship at Sea: A *Problem* of great uſe, whoſe Solution is much to be deſired, and for which there are very ample Rewards allowed.

THERE is nothing that does more ſhow the force and Penetration of Human Underſtanding, than theſe great and wonderful diſcoveries. There is no more certain way of comprehending the Prodigious bulk of the whole Mundane Fabrick, or the amazing Beauty of ſo Divine a Structure, and the Infinite Wiſdom of its Divine contriver; than by conſidering theſe Laws which are lately diſcovered. From them we learn to have a moſt noble and magnificent Notion of the whole Syſtem of Nature. Now we are aſſured that this Earth we Inhabit, is but a ſmall and inconſiderable part of a Glorious Fabrick: Since there are almoſt Infinite Worlds, created by a Supreme and an Almighty Being, which are prodigiouſly larger than ours, in the diſpoſing and governing of which the ſame Being exerciſes his Infinite Power and Wiſdom. *It is He who ſpoke the Word, and the Heavens were made. He commanded and they were created. He hath made them faſt for ever and ever. He hath given them a Law which ſhall not be broken.*

ASTRONOMY is not only uſeful, as it improves the Mind, and by its moſt delightful Speculations, increaſes the Force and Penetration

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of the Underſtanding: But it is likewiſe a conſiderable Help to the perfecting of other Arts and Sciences. In how great Darkneſs would the *Geographers* the *Chronologiſts* wander, were they not aſſiſted with Light from *Aſtronomy?* To it is owing, that we know the Figure and Magnitude of the Earth, and find out the Situations and Diſtances of Places. We learn from it the true Meaſure of the Year, and can give an Account of Actions according to the true Order of the Times in which they happen'd. Hence is evident how uſeful *Aſtronomy* is to Human Affairs; for without it we could have no *Geography* nor *Chronology*, and conſequently no certain Account of Hiſtory,

BUT among all the Arts and Sciences, there is none that has receiv'd greater Improvements from *Aſtronomy* than *Navigation* has done; for by our Knowledge in it we can carry our Ships through the vaſt Ocean in a right Courſe, tho' there is no Tract to be ſeen, and viſit the utmoſt Regions of the Earth. Hence ariſe the Advantages of Trade and Commerce; ſo that whatever Things other Countries afford, that are either precious or delightful, we receive and enjoy without the Inconveniencies of intemperate Heats or Colds, to which thoſe Countries are liable. It is owing to our Skill in Navigation, that our *Britiſh* Monarchs have obtained the Sovereignty of the Seas: So that there is no Nation, at what Diſtance ſoever, but what are kept from doing Injuries to our Countrymen, by the Terrors of a *Britiſh* Fleet.

AS the Art of Sailing does, in a great Meaſure, depend on the Knowledge of the Stars; ſo the impetuous and ambitious Deſires of Kings and Princes, to diſcover unknown and foreign Countries, inclined them to cultivate *Aſtronomy*. The firſt and chief of all the Sailors was *Neptune*, who, upon the Account of his Skill in this Art, was celebrated as God of the Ocean. His Son *Belus*, being an *Aſtronomer*, by his Knowledge therein, carried the Inhabitants of *Lybia* into *Aſia*, where he inſtituted Colleges of *Aſtronomers*; for

Diodorus in the firſt Book of his Hiſtories writes thus: *It is reported*, ſays he, *that the* Egyptian Belus, *the Son of* Neptune *and* Lybia, *brought a Colony to* Babylon, *and there he inſtituted Prieſts, whom the* Babylonians *call* Chaldeans; *who, after the manner of the* Egyptians, *were to obſerve the Stars.* Before his Time, there was *Atlas* King of *Mauritania*, a great *Aſtronomer*, who firſt ſhew'd us the Doctrine of the Sphere. And therefore *Virgil* introduces *Jopas* ſinging what *Atlas* had taught Mankind,

> —— *Docuit quæ maximus* Atlas,
> *Hic canit errantem Lunam Soliſq; labores.*

SO *Uranus*, King of the Country ſituated on the Shore of the *Atlantick* Ocean, for his Skill in *Aſtronomy*, is ſaid to have been deſcended from the Gods. *Zoroaſter* a *Perſian* Philoſopher is celebrated by all Antiquity, as a skilful *Aſtronomer.* And the Honour and Dignity of this Science was had in ſo great a Reputation, as to be called the *Royal Science*, being that Kings were moſt delighted by it above all others. For the Kings of *Africk* and *Syria* firſt invented and improved it, and that long before it was known in *Greece*. This *Plato* acknowledges in his Dialogue, which he call's *Epinomis*. *The firſt*, ſays he, *who obſerved theſe things, was a* Barbarian, *who liv'd in an ancient Country, where, upon the account of the Clearneſs of the Summer Seaſon, they could firſt diſcover them, ſuch as* Egypt *and* Syria, *where the Stars are clearly* ſeen, *there being neither Rains nor Clouds to hinder their Proſpect. And becauſe we are more remote from this Summer clearneſs of Weather than the* Barbarians, *we came later to the Knowledge of theſe Stars.* So *Lucian* tells us, *That the* Ethiopians *firſt took Notice of the Heavenly Motions, and by finding the Cauſes of the Lunations, they knew that the Moon had no proper Light of its own, but borrow'd it from the Sun.* However, it is certain that *Aſtronomy*, from the very beginning was cultivated and im-

proved by the Eaſtern Nations. For if we may believe *Porphyry*, when *Alexander* took *Babylon*, *Caliſthenes*, at the deſire of *Ariſtotle*, carried from that City the Obſervations of 1903 Years, which brings the beginning of theſe Obſervations to 115 Years after the Flood, and 15 Years after the building of *Babel*. *Pliny*, in his Natural Hiſtory relates, that *Epigenes* affirmed that the *Babylonians* had Obſervations of 720 Years, all graven upon Bricks. And *Achilles Tatius*, in the beginning of his Introduction to *Aratus's Phænomena*, informs us, " That the *Egyptians* were the firſt who meaſured " the Heavens and the Earth; and their Science " in this Matter was engraven on Columns, and " by that means delivered to Poſterity. Yet the " *Chaldeans* take the Honour of the Invention to " themſelves, and aſcribe it to *Belus*." The *Greeks* had all their *Aſtronomical* Learning from *Egypt*: For *Laertius* owns that *Thales*, *Pythagoras*, *Eudoxus* and many others went to that Country to be inſtructed in the Sidereal Science: Theſe Men were not only the firſt, but the greateſt Philoſophers that *Greece* produc'd: And from the ſame Author, we know, that they who ſtaid longeſt in that Country, were moſt famous for their Skill in *Geometry* and *Aſtronomy*, after they return'd home: So *Pythagoras*, who liv'd in Society with the *Egyptian* Prieſts ſeven Years, and was initiated into their Religion, carried home from thence, beſides ſeveral *Geometrical* Inventions, the true Syſtem of the Univerſe; and was the firſt that taught in *Greece*, that the Earth and Planets turn'd round the Sun, which was immoveable in the Center; and that the Diurnal Motion of the Sun and fixed Stars was not real, but apparent, ariſing from the Motion of the Earth round its Axis. At that Time no Body was eſteem'd as a Philoſopher, but who was well acquainted with the Mathematical Sciences.

BUT theſe Sciences were ſoon neglected by the Philoſophers that came after them, who much degenerating from their Predeceſſors, had ſo little

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Care and Concern for the Mathematical Sciences, especially *Aſtronomy*, that of all the Obſervations of Eclipſes, for the Space of near 2000 Years, that were ſent from *Babylon* by *Caliſthenes*, *Ptolomy* could not recover but a very few, the reſt being loſt by the Careleſneſs, Negligence, and want of Skill of thoſe Men, who ſhould have preſerv'd them. For theſe Pretenders to Philoſophy, having no Concern for the uſeful Parts of it, ſpent their Time about Trifles, and Diſputes of no Value, and in endeavouring to find out Sophiſms, whereby they would impoſe upon their own and the common Senſe of all Mankind; ſuch were *Zenos*'s Arguments againſt Motion, and moſt of the Philoſophers Diſputations againſt the Diviſibility of Matter *in infinitum*; whereas a little Knowledge of *Geometry* would eaſily have diſſolved all the Difficulties they could raiſe. But tho' *Aſtronomy* was thus baniſhed out of the Schools of the common Philoſophers, yet it was received and cultivated by ſome, tho' but a few, eſpecially by the *Pythagorean* Sect, which flouriſh'd in *Italy* many Years, among whom was *Philolaus* and *Ariſtarchus Samius*. The *Ptolemy*'s Kings of *Egypt* were alſo great Patrons of Learning, they founded an Academy for *Aſtronomy* at *Alexandria*, which furniſhed us with great Men, the chief of whom was *Hipparchus*, who, according to *Pliny*, *undertook a Buſineſs which would have been a great Work to a God to perform, that is, to number the Stars, and leave the Heavens for an Heritage to all that come after.* This Man foretold the Eclipſes of both Sun and Moon for 600 Years; and upon his Obſervations is founded that precious Work of *Ptolemy*, which he call'd his μεγάλη συντάξις, or his great Conſtruction; for from them he gathered the Preceſſion of the Equinoxies, and the Theory of the Planets.

WHEN *Egypt* was conquer'd by the *Sarazens*, and *Alexandria* reduc'd under their Juriſdiction, the Conquerors took *Aſtronomy*, with the reſt of the Liberal Arts, under their Protection; and took care that moſt Part of the Books concerning the

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Liberal Arts and Sciences ſhould be tranſlated from the *Greek* into their own *Arabian* Language.

THE *Sarazens* paſſing from *Africk* into *Spain*, and having a Commerce with the Weſtern *European* Nations, imparted to them the Science of *Aſtronomy*, which before was almoſt loſt in *Europe*; ſo that about the Year 1230, at the Command of the Emperor *Frederick*, *Ptolemy*'s Almageſt, or his great Syntaxis, was tranſlated from the *Arabick* into *Latin*.

AFTER that Time, *Aſtronomy* receiv'd many Improvements from the Patronage of the greateſt Princes, and the Labours of the moſt celebrated Philoſophers; among whom, in the firſt place is to be nam'd, *Alphonſus* King of *Caſtile*, who is never to be forgotten, on the Account of the *Aſtronomical* Tables call'd after his Name. *Nicolaus Copernicus*, was not only a diligent Obſerver, but alſo a Reſtorer of the ancient *Pythagorean* Syſtem. Prince *William*, *Landgrave* of *Heſs*, who procur'd Quadrants and Sextants much larger than what were formerly us'd, to obſerve the true places of the Stars: This Prince's Obſervations are publiſh'd by *Snellius*. Sir *Henry Savill* was moſt skilful both in *Aſtronomy* and *Geometry*, who is ever to be honour'd, for his Munificence in founding our two Profeſſions of *Aſtronomy* and *Geometry* in the Univerſity of *Oxford*, and endowing them with ample Salaries; upon which Account, and many other Benefits he beſtowed on the Learned World, he will always be had in Remembrance with the greateſt Reſpect. That Noble *Dane Tycho Brahee*, who for his Skill in obſerving was ſuperior to all that went before him; and who for the Furniture of his Obſervatory, exceeded even Princes and Kings: He publiſh'd a Catalogue of 770 fixed Stars, which he had diligently obſerv'd. *John Kepler*, a moſt excellent *Aſtronomer*, by the Help of *Tycho*'s Labours found out the true Syſtem of the World, and the Laws the Celeſtial Bodies obſerve in their Motions, with which he vaſtly improv'd *Aſtronomy*; his excellent Works are well

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known to the Learned World, and will ever ſhew how much he is to be praiſed. *Galileus*, the *Lyncian* Philoſopher, who firſt applied a Teleſcope to the Heavens, and by its means diſcover'd a great many new ſurprizing *Phænomena*; as the Moon's or Satellits of *Jupiter*, and their Motions; the various Phaſes of *Saturn*; the increaſe and decreaſe of the Light of *Venus*; the Mountainous and uneven Surface of the Moon; the Spots of the Sun; and the Revolution of the Sun about his own Axis; all which were firſt obſerv'd by this great Philoſopher

I ſhould much exceed the Bounds of a Preface, if I ſhould name the reſt of the great Improvers of our Art, with the Praiſes that are due to them; particularly, Mr. *Hevelius*, who has given us a Catalogue of the fixed Stars, much larger than *Tycho*'s, compoſed from his own curious Obſervations. The moſt Illuſtrious Gentlemen, Meſſieurs *Hugens* and *Caſſini*, who firſt ſaw the Satellits of *Saturn*, and diſcover'd his Ring. *Gaſſendus*, *Horrox*, *Bullialdus*, *Ward*, *Ricciolus*, and many other *Aſtronomers* of great Renown. But we have one here, who on Account of his great Merits in *Aſtronomy*, does excell them all, that is, the moſt Eminent and Learned Dr. *Edmund Halley*, Savillian Profeſſor of *Geometry* in this Univerſity, my moſt friendly Collegue; to whoſe Labours *Aſtronomy* owes many, and thoſe not ſmall Improvements: in him there ſhines out together (which I know not if they are to be found in any other Perſon to ſuch a Degree) the greateſt Dexterity in Practical *Aſtronomy*, and a moſt profound and exquiſite Skill in *Geometry*; which will appear by his *Aſtronomical* Tables, which he is ſhortly to publiſh; for they will far excel all others that ever were, or perhaps ever will be publiſhed.

I could name many others of our own Countrymen, who have done much Service towards the Improvement of *Aſtronomy*; but we muſt not paſs over in Silence the Labours of the celebrated Royal Profeſſor, the late Mr. *John Flamſteed*, who wi[ll]

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indefatigable Pains, for more than 40 Years, watched the Motions of the Stars, and has given us innumerable Obſervations of the Sun, Moon and Planets, which he made with very large Inſtruments, exactly divided by moſt exquiſite Art, and fitted with Teleſcopial Sights. Whence we are to rely more on the Obſervations he hath made, than on thoſe that went before him, who made their Obſervations with the naked Eye, without the Aſſiſtance of Teleſcopes. The ſaid Mr. *Flamſteed* has likewiſe compoſed the *Britiſh* Catalogue of the fixed Stars, containing about 3000 Stars, which is twice the Number that are in the Catalogue of *Hevelius*; to each of which he has annexed its Longitude, Latitude, right Aſcenſion, and Diſtance from the Pole; together with the Variation of right Aſcenſion and Declination, while the Longitude increaſes a Degree: This Catalogue, together with moſt of his Obſervations, is printed on a fine Paper and Character, at the Expences of the late Prince *George* of *Denmark*; but Mr. *Flamſteed*, before he died, had near finiſhed another Edition of them at his own Expence, which I am told will be ſhortly publiſhed.

Among ſo many Helps and Advantages towards the underſtanding of *Aſtronomy*, there was ſtill wanting an Univerſal and compleat Theory of the Celeſtial Phænomena, explained according to their true Motions and phyſical Cauſes. But this Work has been lately performed, finiſhed and publiſhed by the late Dr. *Gregory*, the great Honour of our Profeſſion, and my Preceptor, whom I ought always to remember with Gratitude; for it is owing to him if I have made any Advances in this Study.

IN the mean time it is to be acknowledged, that this Work does not ſeem to be ſuited to the Capacity of young Beginners; for it contains many Things which require an Inſight into deep *Geometry*, ſo as to be clearly underſtood; which Skill is ſeldom to be met with in young Men, who are for all that capable of learning the Elements of *Aſtronomy*. Beſides the Celeſtial Motions and their Phyſical Cauſes are always jointly explained; which

two Things, when they are to be learned by Beginners, diſtracts them too much, and makes the Doctrine difficult. Therefore I thought it more advantageous to the Learner, firſt to explain the Motions, and give an Account of the Phænomena that ariſe from theſe Motions; which, when once underſtood, there will be an eaſy Admiſſion into the Knowledge of Phyſical Cauſes.

FOR which purpoſe, I compoſed the following *Lectures*, which I read in the *Aſtronomical* School at *Oxford*, as my Duty obliged me: In them I have taken ſome Pains, that all the Celeſtial Motions may be clearly explained, and the Reaſons of the Phænomena, which ariſe from thoſe Motions, be given. But particularly of thoſe which are to be underſtood by the help of a few Propoſitions of the Elements of *Geometry*. And therefore I would adviſe our young Beginners, who deſire to learn *Aſtronomy*, that they would place *Euclid*'s Elements before them, when they read theſe *Lectures*, and conſult them when they find any Propoſitions quoted by us. Thoſe we chiefly uſe are but few in Number, ſuch are the 4th. 5th. 8th. 13th. 15th. 27th. 29th. 32d. and 47th of the firſt Element. The 16th. 18th. 20th. 31ſt. 35th. 36th. 37th of the 3d Element: Alſo the 4th. 5th. and 6th of the 6th Element; beſides the Doctrine of Proportion, contained in the 5th Book. It were likewiſe to be wiſhed that the young Student of *Aſtronomy* were skill'd in Plain and Spherical *Trigonometry*. But if there be any, as I believe there are ſome, who deſire to learn *Aſtronomy*, and yet are ignorant of *Trigonometry*; I require of them, that they grant and allow us this *Poſtulate*; Becauſe in every *Triangle*, either Spherical or Plane, there are three Angles and three Sides, of theſe ſix having any three, one of which in a Plane Triangle muſt be a Side, all the reſt may be found. It is *Trigonometry* that teaches us how to perform this, whoſe uſe is apparent in all the Parts of *Aſtronomy*.

THERE are alſo ſome things in our *Aſtronomy*, which require a Knowledge of deep *Geometry*, as when

when we ſpeak of the Elliptick Theories of the Planets diſcover'd by *Kepler.* But I would not have the Beginners or young Students trouble themſelves with theſe Particulars, ſo they may paſs them over.

I deſire alſo, of them that are unacquainted with *Aſtronomy*, that after they have read the XI and XII *Lectures*, concerning the general Cauſes of Eclipſes, they would leave the reſt of that Doctrine, 'till they are inſtructed in the Spherical Inſtitutions, as they are explained by us in the XX and XXI *Lectures*; and then they may return to the remaining Parts of the Doctrine of Eclipſes, contained in the XIII and XIV *Lectures.*

THEY who underſtand what is here deliver'd, may with much Advantage undertake to read that excellent Work of Dr. *Gregory*'s, and learn the Phyſical Cauſes of the Celeſtial Motions from thence.

BOOKS

DR. *Fiddes*'s *Theologia Speculativa & Practica*; or, The First and Second Part of a Body of Divinity under that Title: Wherein are explain'd the Principles, with the Duties of Natural and Reveal'd Religion. In Two Volumes Folio. The Doctor was encourag'd in this Work by the Subscription of Twenty-two Bishops, and above Five hundred Subscribers, among the Clergy and Gentry; also his Degree of Doctor given him by the University of *Oxford* for this excellent Performance. Price of the Two Volumes 2 *l.* 10 *s.*

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ASTRONOMICAL LECTURES.

LECTURE I.

Of Visible and Apparent Motion.

ASTRONOMY being a Science in which are explained the Motions of Bodies that are at an immenſe Diſtance from us, and the Appearances which ariſe from theſe Motions: They who would learn this Science, muſt firſt be informed of the manner how the Motions of diſtant Bodies become viſible, and the Objects of our Senſes.

What Bodies ſeem to be at reſt.

AND firſt it is plain, that ſince the Eye looks upon ſuch Bodies to be at reſt, which keep the ſame viſible Diſtance, the ſame Poſition and Situation, not only in reſpect of other Bodies which we conceive to be at reſt, but alſo in reſpect of the Eye that beholds them; thoſe Bodies can only

Lect. I. be perceiv'd to move, which change their Distances and Positions, in respect to other Bodies, or to the Eye of the Spectator.

What in Motion.

BUT that we may explain this matter by its proper Principles, and draw it from its Origine, that is from an Explanation of the manner of Vision: It must be known, that the writers of *Opticks* demonstrate that every Body which is seen, has its Image painted in the bottom of the Eye, upon that Coat which is call'd Reticular, or the *Retina*, whose Surface is Spherical concave. This Image is made by the Rays of light which flow from the Visible Object to the Eye, and are therein received and refracted: The Image of each Point is in that place, where the innumerable Rays which come from that Point, and passing through the Humours of the Eye, do by Refraction meet on the *Retina*.

Of the Sense of Seeing.

Plate I. Fig. 1.

LET AB, a Portion of the Periphery of a Circle, represent the outward Surface of the Eye; DG the bottom or reticular Coat, which is formed by the Extremities of the Optick Nerves, and let C be the Center of the Eye: The Image of the Point F will be in the Line FCH, and therefore at H: So also the Image of the Point E will be in the Line ECL, at the Point L; for the Rays of Light will, by the pellucid and clear Coats and Humours of the Eye, be so refracted, that all those Rays which come from F, and enter the Eye, will change their Direction and turn towards H, where they will meet; and likewise all those which come from E, being refracted in the Eye, will converge and meet again at L, where they will form the Image of the Point E; for by striking on the nervous Fibres in these Points, they will excite the Sense of Vision.

THERE is a fine Experiment which confirms and demonstrates this Doctrine. For if the Eye of an *Ox*, or any other Creature, just after its Death, be taken out of its Head, and the opake and black Coat call'd the *Choroides*, which covers the back Part of the Eye be separated, so that the thin and pellucid reticular Coat may appear; if this

this Eye be turned towards a Window, or any Object that is strongly illuminated, we shall see with Pleasure and Admiration, a fine Picture on the *Retina*, exactly Representing the Object in its proper Colours: We shall have the same Appearance, if instead of the Eye we take any Convex-glass of a Telescope, and turn it towards the Object, and place a white Paper at a due Distance behind the Glass, we shall observe upon the Paper, an exact Image of the Object, distinctly represented with its lively Colours.

How Motion is perceived by our Eyes.

IF therefore the Image H of the Point F remain unmoved on the same Point of the *Retina*, the Eye being likewise unmoved, the Object F will be at rest: But if the Point F be carried to E, its Image will thereby successively pass thro' different Parts of the *Retina*, and describing the Space H L, will excite the Sensation of Motion. If the Point F be at a great Distance from us, and the Motion be made in a Plain passing thro' the Eye, the Spectator will judge of the Magnitude of the Apparent Motion, by the Magnitude of the Angle F C E.

IF in the Line C F there be another Object M, which is likewise at a great Distance from us, and this Object be carried from M to N, its Motion will Appear to be the same with that of the Object F, for the way of both will Appear the same, the two Images having the same Path, and passing thro' the same Space in the bottom of the Eye: If the visible Point M be carried in the Line C F from M to F, such a Motion cannot be perceiv'd by the Spectator, the Image of M remaining unmoved all the while on the *Retina*: And whatever Bodies are moved in Lines that pass thro' the Center of the Eye, the Motions of such Bodies are not to be Observed by our Sight, nor can we any other way discern such Motions, but by the increase or diminution of the Splendour and visible Magnitude of the Objects. I speak here of distant Objects: For those that are near us, tho' they move in Lines passing thro' the Eye, yet we may discern

Lect. I. their Motions, by the change of Position and Situation which they hold in respect to other Bodies, whose Positions and Distances are known. Now whatever be the Path of the moveable Point F in the Plain FCE, whither it be in the right Line FE, or in the circular Arch FPE, or in any other curve Line FQE; when it comes to the Line CE, its Apparent Motion will always be seen to be the same, while the Angle FCE remains the same, but when the Angle FCE is increased or diminished, the visible Motion will be in like manner increased or diminished, which therefore can be only measured by that Angle.

THAT therefore the Apparent Motions of Bodies may be determined, we must here shew the Method, by which *Geometers* and *Astronomers* find out the Measures of Angles; which tho' it is commonly known, even to the meanest Artists, yet that we may omit nothing which will make what is to follow easily conceived by Beginners, we will here Explain it in a few Words.

The Measures of Angles.

EUCLID has demonstrated that the Angles at the Center of any Circle are proportional to the Arches on which they stand, and therefore the Measures of Angles will be best known from those Peripheries or Arches which subtend them: On which Account the *Astronomers* divide the whole Periphery of a Circle into 360 Parts which are called Degrees, and they divide each Degree into 60 other Parts which are named Scruples, or First Minutes; each of those Minutes are again divided into 60 Second Scruples or Minutes, and each Second is also supposed to be divided into Thirds, each Third into Fourths; and so on.

A Degree what? Scruples or Minutes.

BY this means they reckon no more Degrees or Parts in the greatest Circle than in the least that is, and therefore if the same Angle at the Center be subtended by two concentrical Arches, they count as many Degrees or Parts in the one as they do in the other; for these two Arches have the same Proportion to their whole Peripheries. For Example: Let ACB be an Angle, and from the Cen-

Plate I. Fig. 2.

Center C let there be described two Arches AB Lect. I. DE, subtending the Angle: There are as many Degrees and Minutes contained in the Arch AB, as there are in the Arch DE, altho' the Radius or Semidiameter of the Arch AB were only a Foot long, and the Radius of the other reached the Fixed Stars. It is true indeed, that a Degree in the Arch AB is so much less than a Degree of the Arch DE, as its Radius CB is less than CE or CD: The Angle C is said to be of so many Degrees or Minutes as the Arch which subtends it contains of such Parts.

The Method of Measuring Angles.

THE Instrument by which Angles are observed, is a known Portion of the Periphery of a Circle, as a Quadrant, Sextant, or Octant, that is the fourth Part, sixth Part, or eighth Part of the whole Periphery. If it be a Quadrant, the Instrument-Makers divide it into 90 Degrees, 90 being the $\frac{1}{4}$*th* of 360, if a Sextant, it is divided into 60, which is the $\frac{1}{6}$*th* of 360: If an Octant, it contains 45 Degrees, or the $\frac{1}{8}$*th* of 360: They divide again each Degree into Minutes, and each Minute into Seconds, if the Instrument be large enough to shew such Parts: The Instrument-Makers fix to the Side of the Instrument Pins or Sights, by which they collineat to the Object, and they fasten likewise a Rule moveable about the Center upon the Plain of the Instrument, which Rule is likewise furnished with Sights, with which they observe Angles in this manner.

Plate I. Fig. 3.

LET A and B be two Objects at a great Distance from us: And suppose the Observer at C, who is to measure the Angle ACB: Let the Instrument be turn'd, 'till the Object A can be seen thro' the Sights of the Side CD, and let the Plain of the Instrument be so moved round the Side CD, and the Rule round the Center, that the Object B may be seen thro' the Sights of the Rule: It is manifest from what has been said, that the Arch DE will give the Measure of the Angle ACB, and that the Arch AB will contain as many Degrees, and Parts, as the Arch DE, which the Rule cuts off from the Instrument.

Lect. I. MOREOVER *Astronomers* have other Bounds or Marks from which they reckon the *Arcual* distances of Stars, and Measure them with a like Instrument. These are chiefly the *Horizon*, which is formed by a Plane touching the Surface of the Earth where the Spectator stands, and is infinitely extended towards the Heavens; which it divides into two Hemispheres or Parts sensibly equal, and separates the Visible Heavens from the Invisible. And if we suppose a Circle Perpendicular to this Horizon passing thro' any Star, the Arch of it comprehended between the Star and the Horizon is called the Altitude or Height of that Star. There is another Mark which is called the Pole of the Horizon, and is that Point which is directly overhead, thro' which a Line Perpendicular to the Horizon will pass: And it is in this Line all heavy Bodies endeavour to descend, and according to which we stand upright. By this Method the Sailors at Sea find out the Height of the Sun by the Angle which is formed in the Eye, by Lines coming from the Sun, and from the Horizon. So likewise the *Astronomers* by Rules and Quadrants made on purpose for that use, observe the Angle which the Rays or Lines that come from the Sun or Stars, make with the Line that is Perpendicular to the Horizon.

The Horizon.

The Altitude of a Star.

The Pole of the Horizon.

INSTEAD of plain Sights we now commonly make use of *Telescopes*, for by their means distant Objects are more certainly and exactly observed, than they can be, by our simple View. The manner of fitting *Telescopes* to Instruments, the Method of dividing the Arch, and the Contrivances for managing and moving the Instrument for Practice, we leave to the *Mathematical* Instrument-Makers to describe.

Plate I. Fig. 4.

The Apparent Diameters of Bodies.

BY the Measure of Angles we likewise find the Apparent Diameters of distant Bodies: Let A B be a Line which is seen by the Eye at C directly opposite to it, and suppose drawn from its Extremities A, B right Lines A C, B C to the Eye, that Line A B is said to appear under the Angle

A C B

ACB, which is call'd its Apparent Magnitude, and is said to be so many Degrees and Minutes as that Angle observed by an Instrument contains: After the same way the Object DE, seen by the Eye F, is said to appear under the Angle DFE, and the Apparent Magnitudes of the Lines AB, DE, are to one another, as the respective Angles ACB, DFE.

The apparent Diameters, the nearer we Approach them grow bigger.

BUT if the Eye come nearer to the Object AB, so as to view it but from half the distance, that is from G; the Object will be from thence seen under twice the Angle it appeared under before: If the Eye come three times nearer, its Apparent Magnitude will be near three times greater, provided the Angles be but small, and exceed not a Degree or two: And the Apparent Diameters of such Objects do nearly increase, as the distances from which they are view'd are diminish'd.

Plate I. Fig. 4, 5.

BY this Method, if we know the Apparent Diameters of two Bodies, and the proportion of their distances from us, we can know from thence the proportion their true Diameters bear to one another: For if their distances be equal, their true Diameters will be as their Apparent: And if their Apparent Diameters are equal, their true Diameters will be proportional to their distances. For Example: If the Angle ACB be equal to the Angle DEF, but the distance CB triple of the distance EF, the Line AB will be triple of the Line DE: But if the distance CB be not only triple of the distance *ef*, but also the Angle ACB be double of the Angle *dfe*, the Object AB will be sextuple of the Object *de*: For if we suppose CM equal to *df* and an Object MN, because the Angle MCN; or ACB is double of the Angle *dfe*, MN will be double of *de*; but because CB is triple of CM or *df*, AB will be triple of MN, and consequently it will be six times bigger than *de*. Hence if the Apparent Diameters of the Sun and Moon be equal, let the Sun be 100 times further from us than the Moon, the Sun must needs be 100 times in Diameter bigger than the Moon: We shall afterwards demonstrate that the Sun's

Lect. I. Distance from us is above 100 times greater than that of the *Moon*

IF we know the Apparent Diameter of any Body, we can from thence, exactly know by the help of *Trigonometrical* Tables, what Proportion the Distance of that Body bears to its true Diameter. For suppose the Object DE to be seen by the Eye at F under the Angle DFE. For Example of one Degree; then the Distance FE will be to DE the Diameter of the Object, as the Radius of a Circle is to the Tangent of the Angle DFE; that is supposing DFE one Degree, as 10000 is to 174,5. The Sun appearing under an Angle of about half a Degree, or 30 Minutes, its Distance will be to its own Diameter as 10000 to 87: Hence we are certain that the Sun's Distance from us, is nearly equal to 115 of its own Diameters, And if an Eye were placed in the Sun, to observe the Angle under which the Diameter of the Earth appeared from thence, we then should be able to tell exactly the Distance of the Sun from us, in Diameters of the Earth, or in Miles.

The Advantages of Telescopes.

SINCE, as we have said, the Apparent Diameters of Bodies grow bigger the nearer we come to them, and that they are increased almost in the same Proportion that the Eye approaches them; (for Example: If any Man were ten times nearer to the Moon than we are, and did there observe it, he would see the Moon ten times bigger in its Diameter and clearer than we do; in Diameter I say, for the Surface would Appear 100 times larger than it does to us.) If here on Earth we should take a Telescope which only encreases the Diameter ten times, and look to the Moon with it, the Moon will have the same Appearance seen with such a Telescope, as would appear to a Spectator ten times nearer it than we are. But if we should use Telescopes (and such there are) which Magnifie the Diameters of Objects 100 or 200 times, they will show the Moon in the same manner, figure and bigness, as it would appear in, at a Distance 100 or 200 times less than ours,

Hence

Hence we can perceive with our Eyes with what Face, and how large the *Moon* would show it self, at the Distance of three Diameters of the Earth: As likewise we can discern how it would appear if we approached it much nearer, and view it only at the Distance of 1000 Miles; for from thence we should be able to discover in it vast Ridges of Mountains, deep Caverns, many Vales, and large open Fields. By the means of Telescopes we still ascend higher in the Heavens, and we can approach the Planets, Comets and fix Stars so near, that of such immense Distances, there remains only the hundredth, or two hundredth Part to have the whole Journey finished: And from thence we can behold the Conversions of the Planets about their proper *Axes*; the Moons of *Jupiter* and *Saturn*, their Eclipses; the Belts of *Jupiter*, the wonderful Ring of *Saturn*, and all the various Appearances and Shapes it takes. We could not pass over, without taking Notice in this Place, these advantages of the Telescope, since it is the chief Instrument by which we Observe the Magnitude of the Heavenly Bodies, and their Apparent Motions. Lect. I.

How the Motions of far distant Bodys which are in themselves equal, may appear unequal.

SINCE the Motions of distant Bodies are no other ways to be known, but by the change of the Angle which is at the Eye that observes them; it will easily appear from thence, that tho' Bodies move equally and regularly, describing equal Spaces in equal Times, their Motions notwithstanding may seem to be very unequal and irregular. This will be best understood by an Example.

Plate I. Fig. 6.

SUPPOSE a Body to be revolv'd in the Periphery of a Circle A B D E F G Q, and to move thro' equal Arches A B, B D, D E, E F, in equal Times; and let the Eye be in the Plane of the same Circle, but at a Distance from it, viewing the Motion of the Body from O: When the Body goes from A to B, its Apparent Motion is measur'd by the Angle A O B, or the Arch H L, which it will seem to describe; but in an equal Time, while it moves thro' the Arch B D, its Apparent Motion is deter-

Lect. I. determined by the Angle B O D, or the Arch L M, which is much leſs than the former Arch H L, and the Body when it arrives at D will be ſeen at the Point M of the Periphery N L M: But it takes the ſame time to deſcribe D E which is equal to A B, or B D, and when it arrives at E it is ſtill ſeen at the Point M; ſo that all the time it is moving thro' the Arch D E, it appeares almoſt immoveable, and as it were to ſtand ſtill. While the Body is continually going forward in its proper Orbit, and deſcribing the Arch E F, when it comes to F the Eye in O will ſee it in L, and it will appear to have gone backwards in the Arch M L. So alſo while it moves from F to G, at its arrival at G, it will be ſeen at H in the very ſame Place it appeared in when it was in A. So likewiſe while it paſſes from G thro' I to Q, the Spectator's Eye at O will obſerve it as if it had deſcrib'd the Arch H K N. And tho' it is ſtill going on it is Orbit, while it runs thro' the Arch Q P, the Spectator will obſerve it all that time near the Point N, in a *Stationary* State. After its paſſing by P, and going to A, it will appear to change again its Courſe, and deſcribe the Arch N K H L M with very unequal Motions.

Optical Inequality.

THIS Inequality of Motion is call'd by *Aſtronomers* the *Optical Inequality*: Becauſe it is not really in the Bodies moved, but only Apparent to the Eye which perceives it, ariſing from the Poſition of the Spectator: For the Body all the time moves uniformly forward, and if the Eye were in the Center, it would ſee the Motion always perfectly regularly performed.

Plate I. Fig. 7.

If the Eye be placed within the Circle, the Motion that is equal, may appear Unequal, but the Body can never be ſeen to go backward or to change its Courſe.

IF the Eye were placed in any Point, as O within the Orbit of the Body, but not in the Center, and there the Spectator remained immoveable, he would ſtill obſerve the Motions to be unequal, altho' the Body moved never ſo regularly; and when at the greateſt diſtance from him, as at A, it would appear to be ſloweſt; when it comes neareſt, it would ſeem to move quickeſt. This is plain, for the Arches A B and C D being equal,

they

they will be described in equal times. But the Angle DOC being greater than AOB, the Motion in D will appear swifter than that at A. But in this Case the Body will never appear to stand, or to go backwards, but always forward: And therefore when a Spectator placed within the Orbit of another Body, and viewing its Motion, perceives it sometimes to go forward, then to stand still, and afterwards to go backward, we may from thence conclude that the place of the Spectator is likewise moved. Lect. II.

LECTURE II.

Of the Apparent Motion which arises from the Motion of the Spectator, or Observer.

HITHERTO we have supposed the Spectator to have remained immoveable all the time of the observation: But if the Place of the Observer be likewise moveable, then there will be very different Appearances, and the Eye will perceive those Bodies to be at rest which may have really a very quick Motion, and other Bodies may seem to be in Motion, which remain really at rest: And not only these appearances may be seen, but the Motion of Bodies may appear to be directly contrary to what they truly are, and Bodies which are really going *Eastward* may appear to move towards the *West*. All which will be most easily declared and made plain from the appearances observed by them who Sail in a Ship,

They who Sail in a Ship, perceive not the Motion of the Ship.

SUPPOSE a Ship carried by the Winds with a swift but uniform Motion; the Passengers can neither perceive the Motion in the Ship, nor of any

Lect. II. any thing in it that keeps the ſame relative place in the Ship: For ſince the Veſſel and all its Parts retain the ſame Situation and Poſition in reſpect of the Eye, their Images painted on the *Retina* will always abide in the ſame Place, and therefore they muſt appear unmoved. Hence it is, that tho' every Thing in the Ship goes as faſt forward as the Ship it ſelf does; yet ſuch Motions cannot be perceived by a Spectator that ſits in the ſame relative Place, and who has the ſame common Motion with the Ship. But when the Spectator turns his Eyes towards the Shoar, or upon Objects which are without the Ship, they will ſeem to be moved; for while the Ship goes forward it carries along with it the Eye of the Spectator, by which Motion of the Eye the Poſition of external Objects in reſpect of its ſelf will be changed, and their Images will ſucceſſively occupy different Places on the *Retina*, and therefore Objects without the Ship which are really at reſt will ſeem to be moved, whereas thoſe that are within the Ship, and really in Motion, will appear to be at reſt.

But external Objects without the Ship will ſeem to move.

IF while the Ship is moving very faſt forward a Ball of Lead, or any other heavy Metal, were let fall from the Topmaſt, the Paſſengers in the Ship will obſerve the Ball to fall perpendicularly downwards, and it will fall upon the Deck juſt by the Foot of the Maſt, after the ſame manner as it would fall were the Ship at reſt. But notwithſtanding this, the true Motion of the Ball is not in the Perpendicular, but in an Oblique Line, in which it deſcends; and a Spectator in another Ship which is at Anchor, will eaſily obſerve this Obliquity and Curvity of its way while it falls thro' the Air. The reaſon of this appearance is eaſily ſhewed: For according to the firſt and principal Law of *Natural Philoſophy*, a Body once put into Motion, endeavours to retain that Motion, and to continue moving in the ſame direction. Now the Ball while it was held at the Topmaſt went forward with the Ship, and had its Motion communicated

The Motion of a Ball falling down in a Ship.

to

to it; and therefore after it is left to fall, it will retain the ſame Force to go forward as it did before; and at the ſame time, its Weight carrying it downwards, it will both go forward and deſcend: For the two Forces, one communicated by the Ship, and the other from Gravity, will not hinder or diminiſh one another, they not being contrary. It will therefore be moved as faſt forward, and as much downward as it would be, did the two Forces act upon it ſeparately at different times. By theſe two Forces acting together, the Rectitude of its way is only hindered, which it would have, did the Perpendicular and the *Horizontal* Forces act ſeparately; and the real way of the Ball thro' the Air is a curve Line, exactly like that which a Body takes when it is thrown according to an *Horizontal* direction: And in ſuch a Line it will be obſerved to move, by a Spectator placed near it in another Ship which is at reſt. Beſides, ſince the Ball and Maſt are both moved forward with the ſame Velocity, they will always remain at the ſame Diſtance from each other, and therefore the Ball will touch the Deck juſt by the Foot of the Maſt. Moreover the Motion of the Ball forward is common to the Ship, and all its Parts, as likewiſe to the Paſſengers that are relatively at reſt in the Ship: But we have before ſhewed, that the common Motion could not be obſerved by the Paſſengers in the Ship, and therefore it cannot be perceived neither while the Ball is falling. Wherefore the only Motion that can be ſeen, will be that which is impreſt upon it by its Gravity, which is peculiar to the Ball, and by which it deſcends. And therefore the Paſſengers will ſee the Ball deſcending only in a Perpendicular Line. Experiments have been often made, which demonſtrate that all we have ſaid is exactly true.

The Motion of a Ball thrown within the Ship.

IF any Perſon ſitting at the Ship's Head, ſhould throw a Ball towards the Stern with the ſame Velocity that the Ship goes forward, that ball would neither go forward nor backward; and if there were no Gravity it would remain immoveable:

But

Lect. II. But because Gravity Acts upon it, it will really descend in a Perpendicular Line, and a Spectator in a Ship at Anchor would observe it descending in a Right Line. For the force impreſt upon it when it is thrown, will only deſtroy the firſt force communicated to it from the Ship, to which the Projectile force is contrary and equal. But for all this, the Paſſengers will not perceive this Perpendicular and direct Motion, but they will ſee the Ball go towards the Stern with the ſame force, as it really would have done, had the Ship been at reſt, and the Ball been thrown with the ſame force to the Stern.

BUT if the Velocity with which the Ball is thrown toward the Stern ſhould be leſs than that of the Ship, the real Motion of the Globe will be forward, in the ſame direction in which the Ship goes, but ſlower than it; for the whole Motion communicated by the Ship will not be deſtroy'd, and there will ſtill remain a Part of its former Motion, by which it will be carryed forward, tho' not ſo faſt as before. But the Paſſengers will perceive no ſuch Motion, but they will obſerve the Ball to to be moved in a Line directly contrary to its real Motion, with that very Velocity that it would have, were it thrown when the Ship is at reſt: Hence it is plain that Bodies may appear to have a Motion directly contrary to their real and abſolute Motion.

An Objection. BUT ſome may Object, that the Ball thus thrown, will really hit the Stern of the Ship, and impreſs on it a conſiderable Blow, which it could not do, had it not a Motion towards the Stern. But this difficulty is eaſily removed; for tho' they that are within the Ship ſee the Ball go and hit the Stern, a Spectator without, who is not in Motion, will obſerve that the Ball does not come upon the Stern and give it a Stroak, but that the Stern ruſhes upon the Ball, and acts upon it with all its force: And the force of the ſtroak which each Body receives is the ſame as if the Ship had been at reſt, and the Ball had fallen upon it with

the

Plate I. Fig. 8.

the ſame Velocity that the Stern does really come againſt the Ball; for it is known from the Laws of Motion, that if there be any two Bodies A and B equal or unequal, the force of the Stroak will be the ſame, whither B with a certain Degree of Velocity comes upon A which is at reſt; or if B ſhall be at reſt, and A with the ſame Velocity ruſhes upon B; or if both Bodies move the ſame way, but A moving faſter by its greater Velocity gives B an impulſe, the force of the Stroak will be the ſame as if B were at reſt, and A came upon it with the difference of their Velocities, that is by the exceſs wherewith the Velocity of A is greater than that of B: Or Laſtly, if A and B have contrary Motions, and hit one againſt the other, the greatneſs of the Stroak will be the ſame as if one of them ſtood ſtill, and the other come againſt it with the ſum of their Velocities. In one Word, whatever the real Velocities of the Bodies may be, ſo long as their relative Velocities, or the Velocities by which they approach each other remain the ſame, the force of the Stroak will likewiſe remain the ſame. Hence it is, that in a Ship, however ſwiftly it may Sail, all our Apparent Motions, and the Motions of every thing in the Ship, do all appear to be the ſame that they would, were the Ship at reſt: And it is obſervable that *Flies* and other *Inſects* keep the ſame Motion in regard to one another, whither the Ship is at reſt, or Sails uniformly forward with any degree of Velocity, let it be never ſo great. And it is Univerſally true, that all Bodies that are ſhut up in any one Place, preſerve the ſame Motions in regard of one another, and all appearances will be the ſame, whither the Place remains unmoveable, or has a direct uniform Motion forward.

I have brought theſe Examples that you may perceive how wide the Differences may be between real and Apparent Motions, and how hard it is to judge of real Motions, by thoſe that are ſeen.

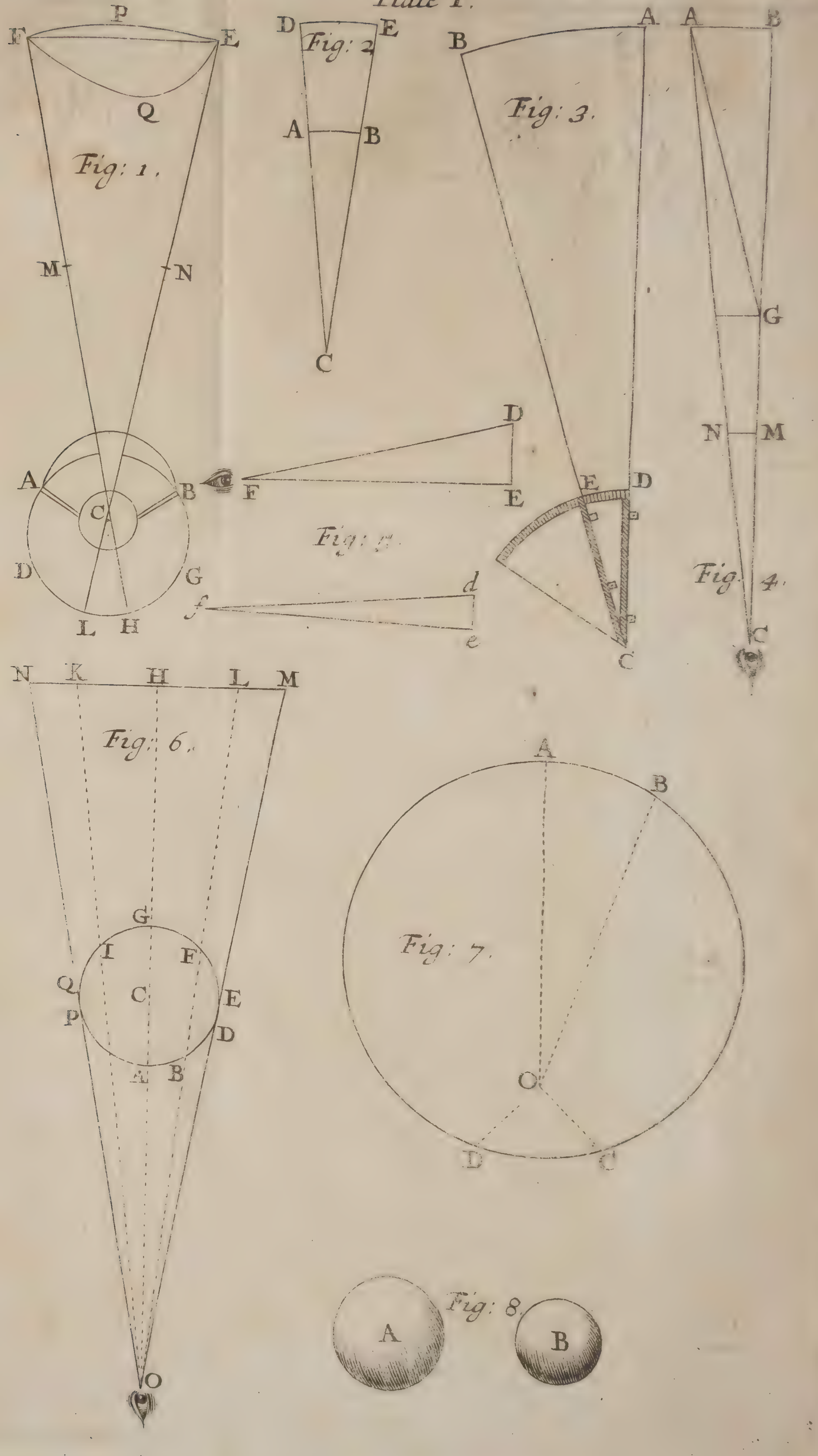
Lect. III. BY this it is evident, that if a Spectator were placed in *Jupiter*, or *Saturn*, or in any other of the *Planets*, he can never be made ſenſible of the Motion of his own Habitation, no more than they who Sail in a Ship can perceive the uniform motion of the Ship. Paſſengers who Sail in Ships may indeed be very ſenſible of the frequent Toſſings and ſudden Shocks the Ship receives from the Waves and Wind, which they find exceedingly troubleſome to them. But the *Planets* which compoſe a Celeſtial Fleet, are not liable to any Storm; they without any Diſturbance or Commotion circulate in their Orbits, and Sail as it were in a moſt Pacifick Ocean, which is continually Calm and Serene.

LECTURE III.

Of the Syſtem of the World.

WE have ſhewed that according to the different Situation and Motions of the Spectator, the Appearances of Things will be very various and different. That we may have a more Diſtinct knowledge of the Fabrick of the *World*, and that the admirable Beauty of the Univerſe, and the harmonious Motions of the Bodies therein contained may be more eaſily underſtood, it will be requiſite that that Divine and Immenſe Fabrick ſhould not be obſerved from one Point or Corner only: But as in Viewing of large Palaces, we take the different Proſpects they afford from ſeveral Places; ſo here to have a true and juſt Notion of the World, we muſt ſuppoſe it to be obſerved in dif-

Plate I.



different Situations and Distances; that by contemplating the various Prospects it gives us, and comparing them together, we may obtain at last a distinct Knowlege of this Immense Palace of *God Almighty*, and have an *Idea* or Image of it impressed on our Minds, which is worthy of its Infinitely wise *Architect*.

FOR to understand therefore the Heavenly Bodies, their Motions, and Appearances, which are called *Phænomena*, we must feign our selves not to be Inhabitants of this *Earth*, and fixed to one Habitation, but suppose we have the Power of Travelling every where, thro' the Immense Regions of indefinite Space; and therefore we will sometimes take Possession of some immoveable Place, from thence we will transfer our selves to the *Sun*, to observe the Regularity and Harmony of the Motions which are to be seen from thence, afterwards we will take a Journey to some other of the *Planets*, that we may from them observe the Apparent Motions of the Heavens; nor will we confine our selves within this *Planetary System*, but we will yet ascend much higher in the Heavens, and view the World from a *Comet* or fix'd *Star*.

We may imagine our selves to have a free Course or Passage thro' all the Parts of the Universe, and of passing from one Star to another.

We, tho' from Heaven remote, to Heaven will move
With strength of Mind, and tread the Abyss above:
And Penetrate, with an Interior Light,
Those upper Depths, which Nature hid from sight.
Pleas'd we will be to walk along the Sphere
Of shining Stars, and travel with the Year.
To leave this heavy Earth, and Scale the Height
Of Atlas, *who supports the Heavenly weight:*
To look from upper Light, and thence Survey
Mistaken Mortals wand'ring from the way.

OVID's *Metamorphosis*, Book XV.

Lect. III. NOW, tho' our Bodies by reason of their Gravity towards the Earth, are detained as it were Prisoners in this earthly Mansion; yet nothing hinders, but that with our Mind and Imagination, we may wander thro' all the Heavenly Regions, and from them Contemplate with the Eyes of our Reason, the whole System of *Nature*. Nor do I see how this liberty of Imagination can be denyed us, which was always allowed to the *Astronomers* of all Ages; for they to observe the equal Motions of the Heavens, thrust the Spectator down to the Center of the Earth, and supposed that the Heavens were viewed from thence, as from the Center of a Crystal *Globe*. An *Astronomer* thinks it no great Concession or *Postulatum*, that he can draw a Line from the *Sun* to the Center of the Earth; and from thence again to any *Planet* or Star. He divides the Heavens with his Circles, and marks out the ways of the Planets; and indeed without such a License he could never have brought *Astronomy* to any degree of Perfection.

AS therefore it was a Custom among the *Astronomers*, to place the Eye in the Center of the Earth, to view from thence the Apparent diurnal Revolution of the Heavens; which would from thence be seen an equable Motion. We will on the contrary, carry the Spectator to some immoveable place in the Heavens; that the real and absolute Motions may be observed from thence as much as they can be, equable and uniform. For the *Astronomers* of all Sects do agree, that the Motions of the Planets are in themselves simple, regular and uniform: But when the Heavens are viewed from the Surface of the Earth, or even from its Center, the Planets seem to be carried by very unequal Motions, and not to observe any regular Course; and therefore we may certainly conclude, that our Earth is not placed in the Center of their Motions. He therefore that would observe the real and proper Motions of these celestial Globes, must first place him-

The Planets seen from the Earth, have unequal and irregular Motions.

himſelf in the Center of the Sun, or in ſome Point or Space not far diſtant from it; and then let him conſider what will be the Appearances or *Phænomena* he will behold from thence.

The Spectator is always in the Center of his own view.

AND firſt it is to be noted, that wherever the Spectator reſides, he will ſtill be in the Center of his own view; for in an indefinite Space, where there is nothing to bound our Proſpect, all Objects that are at a great Diſtance from us, tho' they be at immenſe Diſtances from one another, yet if they appear in the ſame right Line which paſſes thro' the Eye, will be ſeen at the ſame Point of Space; and all Bodies will appear equally remote, when their Diſtances from us become ſo great, that the Eye cannot eſtimate or judge of them: And conſequently the Spectator will look upon them all as placed in the Surface of a Sphere, which has the Eye for its Center, and whoſe Surface is at an immenſe Diſtance, in which Surface, all the heavenly Bodies will ſeem to perform their Motions. Thus tho' the *Moon* be many Millions of Miles nearer to us than the *Sun*, and he again much nearer than the fixed *Stars*, yet all appear as placed in the ſame concave Surface of the Heavens: And even the Clouds which are but a few Miles above us, would be judged to be as far diſtant as the *Moon* and *Sun*, if they did not ſometimes cover them, and obſcure their Light. In whatever place therefore the Spectator reſides, whether it be in the *Earth*, or the *Sun*, or in *Saturn* the furthermoſt of the *Planets*, or even in a fixed *Star*, that place will be looked upon by its Inhabitants as the middle Point of the Univerſe, and the Center of the World; ſince it is the Center of that ſpherical Surface in which all diſtant Bodies ſeem to be placed.

The Proſpect of the World from the Center of the Sun.

A Spectator therefore living in the *Sun*, when he looks towards the Heavens, will obſerve its Surface to be ſpherical concave, and concentrical to his Eye; in which Surface he will obſerve an innumerable multitude of *Stars*, which

Lect. III. we call *Fixed*, every where dispersed throughout the whole Heavens, which like so many gilded Studs, with a bright Lustre adorn the Firmament. These *Stars* we call *Fixed*, because as seen from the *Earth*, they preserve the same immutable Positions and Distances from each other; and so from the *Sun* likewise, they will appear always to retain the same Situations in respect of one another, nearly as they are observed to have when seen from the Earth. For their Distance either from the Earth or Sun is so great, that the little change of place (however great it be when compared to our common Measures) which is made by bringing a Spectator from the Earth to the Sun, will scarcely make any change in the visible Situation of the Stars. Now tho' the fixed Stars seen from the Earth do always preserve the same Distances, Positions and Situations in respect of one another, yet in respect of the Eye we observe them to change their Positions, and sometimes they seem to mount higher in the Heavens, and to come more perpendicularly over us; then they descend again and appear to turn round in Circles, some in greater, some in less, about an Axis which is the Axis of the Earth: And this Circumvolution of theirs is every Night to be observed from the Earth; but whoever would view them from the Center of the Sun, would perceive them absolutely immoveable, and always abiding in the same place of the Firmament. And this Appearance will be the same, whither the Stars do really rest in the same place; or whither the Heavens, in which the Stars are placed together with the Sun, revolved round the Axis of the Earth: For if there were really any such revolution of the Heavens, a Spectator in the Sun would have that Motion in common with the Stars, and therefore he could be no more made sensible of it, than a Passenger in a Ship can observe by his Senses the Course and Motion of the Ship.

The immense Distance of the fixed Stars from the Sun.

The Stars change their Position in respect of the Spectator.

BESIDES the innumerable Stars at rest, there are Six other shining Globes to be observed, which

which perform their circulations round the Sun, in very different Periods of Time: And therefore they must have constantly variable Positions, and be always changing their Distances from one another, as well as from the quiescent Stars. These Globes or Stars are called *Planets*, which signifies *Wanderers*, and one of them is the *Earth*, the place of our Abode. And even tho' we should suppose the Earth to be at rest, and that the Sun did really move round it in the Space of a Year, yet a Spectator in the Sun would observe that the Earth turned round about him; and would see it describe the same Circle in the Heavens, that we in the Earth observe the Sun to perform his Course in; as we shall afterwards demonstrate.

Lect. III.

The six Planets, or Wanderers.

THE Names and Characters, or Marks for the Planets are *Saturn* ♄, *Jupiter* ♃, *Mars* ♂, the *Earth* ⊕, *Venus* ♀, *Mercury* ☿. These Characters were Invented by the *Astronomers* as Abbreviations in writing. The Planets do all turn the same way as the Sun, from the *West* to the *East*, in Orbits which lye in Planes, which are not much inclined to one another, but nearly coinciding: So that the Planes of these Orbits in the Heavens, being little inclined to one another, make Angles with that Circle in which the Earth is seen to turn round the Sun, but of a very few Degrees. As all Planes that are not Parallel, cut one another in right Lines; so the Planes of the Orbits in which the Planets move, cut one another in Lines that pass thro' the Sun's Center; and therefore a Spectator there placed will be in the Plane of each Orbit, and will observe that the Planets moving in the concave Surface of the Heavens, perform their Motions in great Circles, which divide the Heavens into equal Portions. Now the Eye being in this Situation, in the Planes of all the Planets Orbits, can never by that means judge of their different Distances from the Sun; for from thence they will all seem to be at the same Distance from him: And therefore to observe their different Distances,

The Planets turn round the Sun from West *to* East.

Lect. III. as well as Periods, it will be necessary that our Spectator should remove from the Sun, and rise above the Planes of all the Orbits, in a Line Perpendicular to the Plane of the Earth's Orbit; and, for Example's sake: Let us Suppose him to rise so high, as that his Distance from the Sun may equal the Earth's Distance from it, and let him there make his *Astronomical* Observatory: From thence he will not only observe the same fixed Stars in the same Position as before, but he will see both Sun and Planets in the Heavens: The Sun indeed will appear like the fixed Stars, immoveable; but the Planets will be seen to turn round in lesser Circles about him, at very different Distances, and in different Periods: They who finish their Circuits soonest are seen nearest to the Sun, and the Circles they move in are the least; they who take a longer time in revolving describe larger Circles, and are further removed from the Sun; and the order of the Planets will be such as is represented in Figure 1 *Plate* II. Where the Sun remains unmoved in the Center of all the Orbits; round about him six Planets make their Revolutions, *viz.* *Mercury*, *Venus*, the *Earth*, *Mars*, *Jupiter*, and *Saturn*, all from the *West* to the *East*, according to the order of the Letters A B C D. *Mercury* is next the *Sun*, and finishes his Course in three Months: *Venus* in an Orbit somewhat larger, performs her Period in eight Months: Beyond the Orb of *Venus*, is that of the *Earth*, which revolves round the *Sun* in the space of a Year: *Mars* takes two Years to compleat his Circulation: And *Jupiter* at a much greater Distance, does not finish his Revolution 'till after twelve Years: The furthermost and slowest of all is *Saturn*, whose Orbit includes all the others, and requires not much less than 30 Years to compleat his Course.

The order of the Planets.

Plate II. Fig. 1.

The Antient Pythagorean *System.*

THIS was the Antient System of the World, which was at first introduced into *Greece* by the Great *Pythagoras*, and his Disciples, who had learned it from the Wise Men of the *East*, to

whom

whom, as to an University they then all resorted for Instruction. 'Tis true, the other Apparent System, which supposes the Earth immoveable, and the Heavens to revolve about it, was received among the Vulgar and Illiterate part of Mankind; yet the Philosophers retained the true System, 'till *Aristotle* and the Philosophers that came after him, degenerating from their Predecessors, and not being acquainted with true Philosophy, embraced the Common System of the Vulgar: So that the Antient System was forgot, and not minded 'till the time of *Nicolaus Copernicus*, who again brought it to life and retrieved it from Oblivion; and established it by solid Arguments and Reasons: Whence this System is now called the *Copernican System*. After the Invention of Telescopes, the Secundary Planets, with many new and unthought of Appearances, were observed in the Heavens by the *Astronomers*, which did wonderfully enlarge the Antient System, and confirm'd it with invincible Demonstrations.

Lect. III.

The Planets are opake spherical Bodies.

IF a Spectator should with a Telescope more nearly view the Planets, he will soon find that they are spherical Bodies, and opake, like our Earth; having no proper Light of their own, but that they shine with the borrowed light of the Sun; for that side of them which is turned towards the Sun is always illuminated, and it is by the reflected Light of the Sun, that they become visible: But the side opposite to the Sun, which the borrowed Rays cannot reach, remains dark and obscure. And besides this, as all opake Bodies do, the Planets cast a Shadow behind them, which is always opposite to the Sun. The Line in the Planets Body which distinguishes the lucid part from the obscure, is sometimes right, sometimes crooked; and it is sometimes convex towards the Splendid part and Concave on the obscure; sometimes on the contrary, it appears Convex towards the obscure Side and Concave towards the shining Face of the Planet, according to the different Situation of the Eye in respect of the

Lect. III. the Planet, and of the Sun which illuftrates the Planet; which different Pofition is likewife the caufe why fometimes we fee a greater, fometimes a leffer Portion of the illuminated Face; as it ought to be in fpherical opake Bodies which are expofed to the bright light of the Sun.

The Secundary Planets.

THREE of the Planets, *viz.* The *Earth*, *Jupiter* and *Saturn*, have other leffer Planets which continually accompany them, thefe are called Secundary Planets, Moons or Concomitants; for they conftantly keep clofe to their refpective Primaries, and always attend upon them in their Circulation round the Sun; and in the mean time each of them performs his proper Revolution round his proper Primary. The *Earth* indeed has only the *Moon* to keep her company, who never forfakes her in her Annual Courfe round the *Sun*, and while fhe attends upon us, fhe performs proper Circulations of her own round the *Earth*, in the fpace of a Month.

The Earth is accompaned by the Moon.

THAT the *Moon* appears fo large to us, and fhines fo brightly beyond all the *Stars*, and in bignefs feems to equal the *Sun*, is owing intirely to her nearnefs to the *Earth*; for a Spectator in the *Sun*, would fcarcely be able to obferve her without a Telefcope, and therefore if fhe were as far removed from us as the *Sun*, fhe would be fo fmall as fcarcely to be vifible by an Eye that is not affifted by a Glafs.

Jupiter's *four* Moons.

JUPITER has four *Moons* that attend him, which at different Diftances, and with different Periods, perform conftant Circulations round him; that which is next to him, is no further removed than $2\frac{5}{6}$ of his own Diameters, and turns round in one Day, eighteen Hours and an half. The 2d, at the Diftance of $4\frac{1}{2}$ Diameters, defcribes its Orbit in the fpace of three Days, and thirteen Hours. The 3d is removed from *Jupiter*, feven of his Diameters, and finifhes his Circulation in feven Days, four Hours. The furthermoft compleats his Period in the fpace of 16 Days, $16\frac{1}{2}$ Hours, at the Diftance of 12 Diameters of *Jupiter*.

THESE

THESE Jovial Planets were first observed by that Noble *Italian* Philosopher *Galileus*, by the help of the Telescope which he first Invented, and by them he encreased the number of the Celestial Bodies, and called them *Medicean* Stars, in honour of the Dukes of *Tuscany*, with whose Name he dignified them. By the benefit of these new discovered Worlds, *Astronomy* and *Geography* have received many particular Advantages. Lect. III.

Saturn *has five* Moons.

SATURN performs his Course round the Sun with no less than five Attendants, tho' most of them by reason of their great Distance from the Sun, and the smallness of their own Bodies, are not to be seen but by the help of very long Telescopes: The acute Eyes of Mr. *Cossini* the *French* King's *Astronomer*, were the first that reached all that have been already discovered; and but of late they have been seen in *Britain*, by means only of that Telescope which was given to the ROYAL SOCIETY by the Illustrious M. *Hugens*. The Distances of these Planets from *Saturn*, and their Periodical times, are as followeth. The nearest compleats his Revolution in one Day and $\frac{7}{8}$, and is distant from *Saturn*'s Center $4\frac{3}{8}$ of his Semidiameters. The 2d revolves about *Saturn* in 2 Days 17 Hours, and the Semidiameter of his Orbit is $5\frac{3}{5}$ of the Semidiameters of *Saturn*. The 3d finishes his Revolution in 4 Days and 12 Hours, at the Distance of 8 Semidiameters. The 4th compleats his Period in 16 Days, and is distant from *Saturn* 18 of his Semidiameters. The 5th and outermost takes $79\frac{1}{3}$ Days to finish his Course, and is 54 Semidiameters of *Saturn* distant from him.

Saturn's Ring.

BESIDES these Attendants, *Saturn* has an Ornament peculiar to himself, for he is dignified with a *Ring* which surrounds his middle, and does no where touch his Body; but by an exact Libration and Equiponderancy of all its Parts, sustains it self like an Arch, and being thus suspended by *Geometry*, it is kept from falling upon his Body. The Diameter of this Ring, is more than double of

Lect. IV. of the Diameter of *Saturn*; and tho' the thickneſs of this Ring on the convex or concave ſide be but ſmall, yet its breadth or depth is ſo great, that it takes up the half of that Space which is between its outward Surface and the Body of *Saturn*, the reſt of the Space remaining void: So that in proper Situations we can ſee the Heavens between the Ring and the Body. For what purpoſe this admirable Ring was made, we know not; and perhaps we never may come to the Knowledge of it, ſince we find nothing in Nature like it: But yet we cannot but admire the Infinite Majeſty and Power of GOD, who in this our Age, has diſcovered and ſhewed us new and unthought of Inſtances of his Greatneſs.

LECTURE IV.

In which is proved that the Syſtem Explained in the former Lecture, *is the true Syſtem of the World.*

IT may perhaps be objected againſt the Syſtem of the World delivered in our laſt Lecture, that we feigned and imagined our Spectator carried up into Heaven, and from thence to have ſeen with his Eyes the Motions, Situations, and Order of the Planets which we there Explained. But this was only done in Imagination, and therefore being nothing but a Fancy or Fiction, the Syſtem we have given upon that Suppoſition, will be likewiſe only a Fiction or Hypotheſis, and may not anſwer to the Reality of Things. Can there not, by the ſame liberty of Fancy, any other Order of the Planets be ſuppoſed, and another Syſtem be given quite different from ours? Cannot

not we relying upon our Senses, place the Earth in an immoveable Position, and suppose the Sun and Planets, and all the Stars to move round it, as our Eyes testifie to us that they do, and from such Positions cannot we explain all the Appearances of their Motions?

I Answer, that altho' we fancied our Spectator raised up to the Heavens, and from thence to have looked upon the Sun and Planets; yet the Order, Motions and Positions of the Planets, which would be seen upon that Supposition, and which we explained in the preceding Lecture, is no Fancy, or Fiction of the Imagination, but is as real, certain, and indubitable, as if a Spectator were there, and saw it with his Eyes. A true *Astronomer* feigns nothing without solid and sufficient Reasons, he takes Nature for his Guide and Rule, and lays his foundations on Observations: He raises his System upon Physical Causes, and invincible *Geometrical* demonstrations, with which, as with an indissolvable Cement, he joins and binds the whole Fabrick together. The *Hypotheses* of *Ptolemy* and *Tycho* may truly be called Fictions, for they have nothing in them but a bare Supposition, on which without any reason they depend; and they distort, and disorder the whole frame of Nature. But the true *Astronomy* is the most Antient of all, for it was preserved in the School of the *Pythagoreans*, to whom it was delivered by the first *Astronomers*, either *Ægyptians* or *Chaldeans*: It has all its Parts fitly joined together in a most agreeable Harmony and Order; it leads us to the knowledge of the Universe, and the wonderful Symmetry, Beauty and regular disposition of all the Bodies that compose it. There is nothing in Nature that does more show the peircing Force of Human Understanding, the sublimity of its Speculations and deep researches, than true *Astronomy*. It raises our Minds above our Senses, and even in contradiction to them, shows us the true System of the World: The faculty of Reason by which we have

True Astronomy admits of no Fictions, or Hypotheses.

made,

Lect. IV. made these great discoveries in the Heavens, must needs be derived from Heaven, since no Earthly Principle can attain so great a Perfection. And since the Origination of our Minds is from Heaven, it may be expected that they will endeavour to return thither, and Heaven will become our final Habitation: We will here declare in few Words, some of the ways by which the Mind arrived to the knowledge of these Heavenly discoveries.

A Demonstration that the Planets turn round the Sun.

FIRST, it is certain that wherever the Sun be placed the Orbit of *Venus* does surround him, and includes him within it self; and therefore *Venus* while she describes this Orbit, does really turn round the Sun; for *Venus* has been observed to be above or beyond the Sun, sometimes it has been seen below it or between the Sun and us. That *Venus* ascends above the Sun is plain from hence, that when she is in Conjunction with the Sun, that is when she is seen from the Earth near the same part of the Heavens that the Sun is in, her lucid Face appears in a full and round Figure: For since all the Planets borrow all the Light with which they shine, from the Sun, it is necessary that that Face of hers should be lucid which is towards the Sun, and that which is turned from him, be involved in Darkness; and therefore when she Shines with a full and round Face, that side of her which is towards the Sun is also towards the Earth; and therefore at that time she must be above the Sun, for in no other Position could her illuminated Face be towards the Earth, when she is seen in Conjunction with the Sun. In the Figure let S represent the Sun, T the Earth, and let *Venus* be in F or V, where she can be seen from the Earth, in the same part of the Heaven that the Sun is, and she will appear to have a full and round shining Face; because that side of her which is illuminated, and is towards the Sun, is likewise turned towards the Earth; and therefore the Place of *Venus* in that case, must necessarily be above the Sun. That

Plate II. Fig. 2.

Venus

Venus is alſo ſometimes below the Sun, or between the Sun and us, is evident from hence; that ſometimes when ſhe is in Conjunction with the Sun, ſhe either quite diſappears, or if ſhe is viſible, ſhe appears Horned and takes exactly the ſhape of a new Moon: And therefore that Face of hers which is towards the Sun, either is wholly turned from the Earth as in G; or only a very ſmall part of the illuminated Face is towards the Earth, and can be ſeen by its Inhabitants, in which caſe ſhe aſſumes a horned Figure as the Moon does; and therefore at that Time ſhe muſt of neceſſity be placed between the Sun and us, and come lower or nearer to us than the Sun is. Once *Venus* was ſeen within the body or disk of the Sun; but there was but one Man who had the happineſs to be witneſs of the Sight, our Country-Man Mr. *Horrox*, who in the Year of Chriſt 1639, obſerved it with his Teleſcope to enter upon the Body of the Sun like a black Spot. This is a Sight which can ſeldom be obſerved, for it will not be ſeen again in the Sun's Body, 'till the Year 1761, upon the 26th day of the Month of *May* in the Morning, at which time all our *Aſtronomers* will no doubt be buſie in making their Obſervations; for by them our Diſtance from the Sun can be nearly determined, which before that Time is not eaſily to be aſcertained. Beſides this, *Venus* is always obſerved to keep near the Sun, and in the ſame quarter of the Heavens that he is, for ſhe never recedes from him beyond a certain Diſtance of about 45 Degrees; that ſo ſhe never comes in Oppoſition to the Sun, or to be ſeen in the *Eaſt* when he is in the *Weſt*; nay, ſhe never attains or arrives at a Quartile Aſpect with him, or to have a fourth part of the Heaven between her and him, which would neceſſarily happen, did ſhe perform her Period round the Earth in either a longer, or ſhorter time than the Sun does.

Lect. IV.

The Appearances of Mercury *are like thoſe of* Venus.

AFTER the ſame manner *Mercury* always keeps himſelf in the Neighbourhood of the Sun, and never recedes from him ſo far as *Venus* does, he

Lect. IV. he hides himself so much in the Splendor of the Sun's Rays, that he is but seldom seen by us on the Earth; but since the Invention of Telescopes, he has been frequently observed, when in Conjunction with the Sun, to pass under his disk like a black Spot, as *Venus* was seen by Mr. *Horrox*: The exceeding Brightness by which *Mercury* out-shines all the Planets, does evidently prove him to be much nearer the Sun, than any of the rest; for the nearer any Body is to the Sun, the greater is the Illustration it received from him. From all this it is evident, that *Mercury* does likewise go round the Sun in a lesser Orbit, included within the Orbit of *Venus*; which therefore must necessarily be his Place, for no other can be assigned him.

The Orbit of Mars *includes the* Sun *within it, and likewise the* Earth.

MARS is not like *Mercury* and *Venus*, for he often comes in Opposition to the Sun, and appears to Rise in the *East*, when the Sun Setts in the *West*, and therefore his Orbit includes the Earth within it, and not only the Earth, but it necessarily includes the Sun likewise; for *Mars* when he is seen near the Conjunction with the Sun, if he were between the Sun and Earth, would either quite disappear, or appear Horned in the same Shape that *Venus* and the Moon have in that Position: But he always preserves a full, round and shining Face, except near his *Quadrat Aspect*, that is, when there is about a fourth part of the Heavens between the Sun and him; then he is observed to be somewhat gibbous, like the Moon, three or four days before or after the *Full*.

Plate II. Fig. 3.

LET S represent the Sun, T the Earth, and the Circle MNPR the Orbit of *Mars*; it is plain that *Mars* in both M, and P, must shine with a full Face upon the Inhabitants of the Earth, because that in both these Positions his Face, which is towards the Sun, and by it Illuminated, is likewise towards the Earth: But in N and R, he will appear a little gibbous or deficient from Full. Besides *Mars* when he is seen in Opposition to the Sun, looks almost seven times larger, in

in Diameter than when he is near to a Conjunction with him; and therefore he must needs be seven times nearer to the Earth in the one Position than in the other: From hence it is plain, that tho' the Earth lies within the Orbit of *Mars*, yet it is not near to the Center of his Orbit; but *Mars* always keeps nearly at the same Distance from the Sun, and therefore it is evident, that it is not the Earth, but the Sun which *Mars* respects as the Center of his Motions: For *Mars* seen from the Earth appears to move very unequally, sometimes to go faster, sometimes slower, sometimes he scarcely seems to move at all, and sometimes he even goes with a backward Motion; whereas a Spectator in the Sun, would always see *Mars* go forward in the same uniform tenor, and therefore it is most evident that the Sun is the Center, and not the Earth, of *Mars*'s Motions. Again, since the same Appearances are observed in *Jupiter* and *Saturn*, as in *Mars* (tho' the disproportion, or difference of the Distances is not so great in *Jupiter* as in *Mars*; nor so great in *Saturn* as it is in *Jupiter*) and the Motions of these two Planets are no ways uniform round the Earth; yet from the Sun their Motions will be seen to be regular and orderly: It is plain from hence that the Sun, and not the Earth, is in the Center of all the Orbits of the Planets. The place of the Earth we have demonstrated to be without the Orbits of *Mercury* and *Venus*, and within the Orbit of *Mars*; and therefore its Place must needs be between the Orbits of *Venus* and *Mars*: And from thence it follows, that the Earth it self must turn round the Sun, for if it stood still, since it lies within the Orbits of the superior Planets *Mars*, *Jupiter*, and *Saturn*, we might indeed observe the Motions of those Planets from the Earth, to be very unequal and irregular, but they would never appear to stand still, or to go backwards, so long as the Orbits themselves are quiescent, as we demonstrated in our first Lecture. Since therefore the Stations, and Retrogradations

Lect. IV.

The Earth *is not in the Center of* Mars's *Orbit.*

The same Appearances of Jupiter *and* Saturn.

The Earth *moves in an Orbit round the* Sun.

 tions of these Planets are observed from the Earth: and since the Position of the Earth, or place that it obtains in the System, is in the middle of the moveable Bodies, having *Mercury* and *Venus* on one side nearer to the Sun, and *Mars*, *Jupiter*, and *Saturn* on the other side more remote; it being of the same nature as they are, must likewise have the same sort of Motions; and as the Earth is in the middle place between *Venus* and *Mars*, so its Period likewise in which it performs its Course round the Sun, is also a mean between the Periods of *Venus* and *Mars*, being greater than the one, and less than the other: For *Venus* describes her Orbit in eight Months; the Earth in a Year; but *Mars* takes near two Years to finish his Course.

A Demonstration of the Earth's Motion.

THERE is another demonstration of the Earth's Motion drawn from Physical Causes, for which we are indebted to the admirable discoveries of the Incomparable *Sir* ISAAC NEWTON: He has demonstrated that all the Planets Gravitate towards the Sun: And observations testifie to us, that either the Earth turns round the Sun, or the Sun round the Earth, in such a manner as that they describe equal *Area's* in equal Times. But *Sir* ISAAC has demonstrated that when ever Bodies turn round each other, and regulate their Motions by such Law, the one must of necessity Gravitate to the other; and therefore if the Sun in its Motion does Gravitate to the Earth, Action and Re-action being equal and contrary, the Earth must likewise Gravitate to the Sun: He has likewise demonstrated that when two Bodies Gravitate to one another, without directly approaching one another in right Lines, they must both of them turn round their common Center of Gravity. The Sun and Earth therefore do both turn round their common Center of Gravity. But the Sun is so great a Body in respect of the Earth, which is but a Point as it were in comparison of the Sun, that the common Center of Gravity of the Earth and Sun, must lye within the Body of the

Sun its ſelf, and not far from the Center of the *Sun*: The *Earth* therefore turns round a Point which is within the Body of the *Sun*, and therefore turns round the *Sun*. This Argument drawn from Phyſical Cauſes I take to be unanſwerable. Lect. IV.

COMPARING the Periods of the *Planets*, or the Times they take to finiſh their Circulations, with their Diſtances from the *Sun*, we find they obſerve a wonderful Harmony and proportion to one another; for the nearer that any *Planet* is to the *Sun*, the ſooner does he finiſh his Circulation, and his Motion is the quicker: And in this there is a conſtant and immutable Law, which all the Bodies of the Univerſe inviolably obſerve in their Circulations. *Viz.* That *The Squares of their Periodical Times, are as the Cubes of their Diſtances from the Center of their Orbits, about which they perform their Motions regularly.* The moſt ſagacious *Kepler* was the firſt who diſcovered this great Law of Nature in all the Primary *Planets*; afterwards the *Aſtronomers* obſerved that the Secondary *Planets* did likewiſe regulate their Motions by the ſame Law; and that in the two Syſtems of Bodies revolving about *Jupiter* and *Saturn*, this Rule is conſtantly obſerved, that the Squares of their Periodical Times are as the Cubes of their Diſtances from their reſpective Primaries. Thus the *Moon* or *Satellite* that is next to *Jupiter*, is diſtant from *Jupiter*'s Center $2\frac{5}{6}$ of *Jupiter*'s Diameters, and he performs his Period in 42 Hours. The outermoſt *Satellite* deſcribes his Orbit in 402 Hours. Say therefore as 1764 the Square of 42, is to 161604 the Square of 402; ſo is $\frac{4913}{216}$ the Cube of $2\frac{5}{6}$, to a fourth proportional Number, which by the *Golden Rule* will be found nearly $\frac{450000}{216}$; out of which number extract the cube Root, and we have $\frac{76}{6}$ or $12\frac{2}{3}$ for the Diſtance of the furthermoſt *Satellite* from *Jupiter*. Now the Obſervations of all *Aſtronomers* confirm, that this is the true Diſtance of that *Satellite* from the Center of *Jupiter*, and the ſame thing is to be obſerved in

A wonderful Harmony obſerved between the Periods of the Planets, *and their Diſtances from the* Sun.

Lect. IV. in all the reſt, as likewiſe in the *Satellites* of *Saturn*.

THE reaſon of this Law was unknown to *Kepler*, for he found it out only by Computation, comparing the Diſtances of the *Planets* with their Periods. But the Glory of inveſtigating it from its proper Cauſe, and demonſtrating the Phyſical Neceſſity of this Law, was reſerved for the Great *Sir* ISAAC NEWTON, who has demonſtrated, that without a total Subverſion of the Laws of Nature, no other Rule could take place in the Circulations of the Heavenly Bodies.

Sir Iſaac Newton *firſt diſcovered the reaſon and Cauſe of this Harmony.*

SINCE therefore all *Aſtronomers* do unanimouſly agree that the Law we have above explained is conſtantly obſerved by 14 great Bodies, of which there are more than one that turn round a common Center, *viz.* five Primary *Planets* and nine Secondaries. And ſince the *Moon* turns round the *Earth*, if the *Sun* did likewiſe perform his Circuits round it, according to this Law of Nature, the *Moon* and *Sun* ought to regulate their Motions in the ſame manner; and therefore ſince the *Moon* finiſhes her Courſe in 27 Days, and the *Sun* in 365, and the Diſtance of the *Moon* is known to be about 60 Semidiameters of the *Earth*; if we ſay, as 729 the Square of 27 is to 133225 the Square of 365, ſo is 216000 the Cube of 60 to another which will be 39460356, the cube Root therof being 340 ought to expreſs the Diſtance of the *Sun* from the *Earth*, provided he governed his Motion by the ſame Law that all other Bodies do. Now the *Aſtronomers* prove by invincible Reaſons that the *Sun* is more than 30 times further from the *Earth* than 340 Semidiameters of the *Earth*; for it cannot well be ſuppoſed ſo little as 10000 Semidiameters: According to which Diſtance it could not turn round the *Earth* in leſs than 54700 Years, if it obſerved the ſame Law which all other Bodies do.

NOW

NOW it is certain that the *Sun* does either turn round the *Earth*, or the *Earth* round the *Sun* once in a Year. But if the *Sun* ſhould be made to turn round the *Earth*, the Univerſal Law of Nature would thereby be violated, the Harmony and Proportion of the Motions deſtroyed, and a Confuſion and diſorder introduced into the Frame of the Univerſe. But if the *Earth* be made to go round the *Sun* in the ſpace of a Year, it will then perform its Circulation according to the ſame Law which the other *Planets* obſerve; and without the leaſt exception there will be a moſt beautiful order and Harmony of Motions every where preſerved thro' the whole Frame of Nature.

Lect. IV.

If the Sun *turned round the* Earth, *this Harmonical Rule would not univerſally hold.*

AS we diſcover the mutual Relations and likeneſs of Nature that is in the *Planets*, in that they are like our *Earth*, Opake, Spherical Bodies, which are illuſtrated and ſhine with the borrowed Light of the *Sun*, round whom they all Circulate, as we have ſaid, with a regular Harmony and order: So likewiſe the *Sun* and all the *fixed Stars* which ſhine with their own native Light, and remain immoveable in their Places, are to be conſidered as Bodies of the ſame kind and Nature: The reaſon why our *Sun* appears to us ſo great and bright in compariſon of the *Stars*, whoſe weaker Lights diſappear as ſoon as the *Sun* begins with his Beams to refreſh and illuſtrate our Habitation, is, that the *Earth* at an immenſe Diſtance from all the reſt of the *Stars*, keeps near to the *Sun*, round whom ſhe always circulates; for a Spectator placed as near any of them as we are to our *Sun*, would ſee a Body as big and bright as the *Sun* appears to us, and every way like our *Sun*. A Spectator as far diſtant from our *Sun* as the *fixed Stars* are from us, would obſerve our *Sun* as ſmall as a *Star*, and no doubt would reckon the *Sun* as one of them in numbering the *Stars*. All the *fixed Stars* therefore are *Suns*, and the *Sun* differs in nothing from a *fixed Star*.

Lect. IV. ALTHO' the *Earth* is at ſuch a Diſtance from the *Sun*, that if it were to be ſeen from his Body it would appear no bigger than a Point, yet that Diſtance is ſo very ſmall in compariſon of the exceeding great Diſtance of the neareſt *fixed Star*, that if the whole Orbit, in which we have ſaid the *Earth* moves round the *Sun*, were ſeen from a *Star*, it would appear likewiſe no bigger than a Point. For the Angle under which the whole Diameter of the *Earth*'s Orbit appears is ſo very ſmall, that our quickeſt and moſt ſharp ſighted *Aſtronomers* can ſcarcely obſerve it. They who have been moſt diligent in obſerving this Angle (which they call the Parallax of the great Orbit, that is of the Orbit in which the *Earth* moves) have always found it to be leſs than a Minute, and therefore the *fixed Stars* muſt be at leaſt 10000 times further from us, than we are from the *Sun*.

HENCE it follows, that tho' the *Earth* approaches nearer to ſome *fixed Stars* at one time of the Year, than it does at the oppoſite Time, and that by the whole interval of the Diameter of its Orbit, the *Stars* will not upon that account ſeem bigger when it is neareſt to them, nor will the viſible Poſition of any two *Stars* be ſenſibly changed by the Motion of the *Earth*. For even here on *Earth*, if there be two Towers that are near to one another, if they are to be ſeen by a Spectator who is ten Miles diſtant from each, if this Spectator approach near to them only by one Pace, which is the 10000th part of the Diſtance, he only approaching by ſo ſmall a Space, can no ways perceive the Towers bigger, or their Diſtance from one another greater. After the ſame manner the *Earth* approaching a *fixed Star*, and coming nearer to it by the 10000th part of the Diſtance between the *Earth* and it, a Spectator on the *Earth*, upon the account of ſo ſmall a change of Place, will not find thereby any ſenſible difference either of the Magnitude, or Poſition of the *Star*.

HENCE

HENCE it follows, that if the *Sun* were as far diſtant from us as the *Stars* are, that is 10000 Semidiameters of the *Earth*'s Orbit, it would appear 10000 times leſs or under a ſmaller Angle than it does now: Now the Angle under which the *Sun* appears to us, is about half a Degree or 30 Minutes; if the *Sun* were removed as far from us as the *fixed Stars* are, he would be ſeen under an Angle of but the thouſandth part of three Minutes, that is under an Angle no bigger than ten *Thirds*, which is altogether imperceptible; and no bigger would the Angle be under which a Spectator placed among the *fixed Stars* would obſerve the *Sun*.

The Angle under which the Sun *would appear ſeen from a* fixed Star.

AGAINST this Poſition of ours ſome may object, that if the Diſtance of the *Stars* be ſo great, they themſelves muſt be vaſtly larger than our *Sun*; for they cannot according to them be leſs than a Sphere, whoſe Semidiameter equals the Diſtance between the *Sun* and us; for they aſſert that the *Stars*, at leaſt thoſe of the firſt Magnitude, are ſeen under an Angle at leaſt of one Minute: But the Orbit of the *Earth* ſeen from the *fixed Stars* does not ſubtend a greater Angle, and therefore the Diameter of the *Stars* is not leſs than the Diameter of the *Earth*'s Orbit. Now that Sphere whoſe Semidiameter equals the Diſtance between the *Sun* and *Earth*, is ten Millions of times greater than the *Sun*; conſequently the *fixed Stars* muſt be at leaſt ten Millions of times greater than our *Sun*: Since therefore there is ſuch enormous difference in their bigneſs, it cannot be ſuppoſed that the *Sun* and *fixed Stars* are Bodies of the ſame kind.

The fixed Stars *have no Apparent Diameters, but look like Points.*

BUT they who aſcribe ſuch immenſe Magnitude to the *fixed Stars*, are much deceived in their Meaſures, for their Apparent Diameters are not near ſo great as they ſuppoſe them to be: For really theſe Diameters are ſo extreamly ſmall, that if they be rightly obſerved, they appear like ſo many ſhining Points without any Breadth or Diameter at all; and there can be no Obſervations

Lect. IV. nice enough, by which the minuteneſs of their Diameters can be meaſured, or reduced to any determined quantity. We obſerve about all flaming and ſhining Bodies in the Night, a kind of irradiation or luminous Appearence, by which their Diameters are ſeen a Hundred or many more times bigger than they are; as it is plain by the Experiment of a Candle placed at a great Diſtance, whoſe Flame ſeems to be much larger than it is when we come near it. This irradiation is much diminiſhed if they are looked at thro' a ſmall hole made with a Pin in Paper, but it is eaſier and more nicely taken away when they are ſeen thro' a Teleſcope, which deſtroys the adventitious Rays, and ſhews us the *fixed Stars* as ſo many lucid Points. Now tho' Teleſcopes do encreaſe the Diameters of Bodies very much, yet the *fixed Stars* ſeen thro' them appear ſtill ſo ſmall, that we have no meaſure of any determined Magnitude but what is greater than theirs ſeem to be; a Teleſcope magnifying a Hundered times ſhews them only like ſhining Points; and therefore I cannot but wonder why *Riceiolus* ſhould ſuppoſe the Apparent Diameter of the *Dog-Star* or *Sirius* to be 18 Seconds; for if that were the Angle he ſubtended to the naked Eye, a Teleſcope which Magnifies 200 times, would ſhew that *Star* under an Angle of 3600 Seconds or one Degree, ſo that he would appear to have a Disk four times greater than the *Sun* and *Moon* have: And yet Obſervation teſtifies that ſuch a Teleſcope ſhews us *Sirius* no bigger than a Point, at leaſt not larger than the Planet *Mars*: But *Mars*, when he is neareſt us and biggeſt, ſubtends an Angle of about 30 Seconds; therefore if the Diameter of *Sirius* magnified 200 times is but 30 Seconds, its Apparent Diameter without magnifying will be the 200th part of 30 Seconds, or $\frac{3}{20}$ of a Second, that is nine Third Scruples or Minutes, or nearly equal to the *Sun* when it is ſeen at the Diſtance of the *fixed Stars*, as we ſhewed before: The

Which is demonſtrated by the Teleſcope.

Sun

Sun therefore and *Sirius* are nearly of the ſame Lect. IV. Magnitude and Dimenſions, and may be eſteemed Bodies of the ſame kind.

SINCE the *fixed Stars* appear ſo ſmall, and ſubtend at the Eye ſuch unperceiveable Angles, ſome will wonder how they come to be at all ſeen, ſince there are Bodies which would ſhow themſelves under larger Angles that are yet ſo ſmall, as not to be looked at without a Microſcope: But all flaming and fiery Bodies can be ſeen at great Diſtances, even at ſuch from whence other Bodies which have as large apparent Diameters do quite diſappear, and become Inviſible. Thus the Flame of a Candle in the Night time is eaſily perceived at the diſtance of two Miles, whereas in the Day time an opake Object, tho' ſtrongly illuſtrated by the *Sun*, and ſix times bigger than the Flame of a Candle, is not to be obſerved with the naked Eye at that Diſtance. For the native Light that theſe fiery and flaming Bodies ſend forth, is ſtronger and more peircing, and acts upon the nervous Fibres of the *Retina* with a greater Force, than the Light reflected from opake Objects; for all Light is much weakened by Reflection. And it is upon the account of this brisk and ſtrong Light which flows from fiery Bodies, and which makes ſo ſenſible Impreſſions on the *Retina*, that ſuch Bodies are judged to be ſo big in compariſon of others which affect us with a weaker Light.

The fixed Stars *are Luminous fi.ry Bodies.*

HENCE it is evident that all theſe *Stars* which remain immoveable in the Heavens are Bodies of a fiery nature, as our *Sun* is, nor are they much leſs, nor much bigger than he is, and therefore are to be eſteemed as ſo many *Suns*. It is not to be imagined that all theſe *Suns* are planted in one concave Surface of a Sphere, ſo as to be all equally diſtant from us; but it is more reaſonable to ſuppoſe that they are ſpread every where thro' the vaſt Indefinite ſpace of the Univerſe, and that they are at great Diſtances from one another; ſo that there may be as great Diſtance

The fixed Stars *are* Suns.

Lect. IV. between any two *Suns* that are next to one another, as there is between our *Sun* and the nearest *fixed Star*. Hence a Spectator who is near any one *Sun*, will only look upon him to whom he is nearest as a real *Sun*, and the rest he will consider as so many small shining *Stars* fixed in his Heaven or Firmament.

IT is no ways probable that GOD Almighty who always acts with infinite Wisdom, and does nothing in vain, should create so many *Suns*, and place them alone in indefinite Space, at such great Distances from each other, and not have made other Bodies, which he has placed near them, to be nourished, animated and refreshed with the Heat and Light of these *Suns*: Those who affirm that GOD created these great Bodies only to give us a small dim Light, must have a very mean Opinion of the Divine Wisdom. It is more reasonable to suppose that every *Sun* is surrounded with a company of *Planets*, peculiar to himself, which in different Periods, and at different Distances, perform their Circulations round their proper *Sun*; and who knows but that some of these *Planets* may have *Moons*, and other Bodies to attend them in their Circulations?

An Idea of the Universe.

HENCE we may frame to our selves an admirable Magnificent *Idea* or Notion of the vastness or Amplitude of the World, by imagining an Indefinitely great Space of the Universe in which there are placed innumerable *Suns*, which tho' they appear to us like so many small *Stars*, yet are Bodies which are not behind our *Sun* either in Bigness, Light, or Glory; and each of them constantly attended with a number of *Planets*, which dance round him, and constitute so many particular *Worlds* or Systems: Every *Sun* doing the same Office to his proper *Planets* in illustrating, warming, and cherishing them, that our *Sun* performs in the System to which we belong.

HENCE we are to consider the whole Universe as a glorious Palace for an infinitely Great and every-where-present GOD; and that all

the

the *Worlds* or Syſtem of *Worlds*, are as ſo many Theaters, in which he diſplays his Divine Power, Wiſdom and Goodneſs. Lect. V.

LECTURE V.

Of the Solar Spots. Of the Rotation of the Sun *and* Planets *round their* Axes: *And of the* fixed Stars.

UPON the account of the great Diſtance of the *Sun* from us, the convexity of his Body cannot be perceived by our ſight; nor is this a wonder, ſince the *Moon* which is much nearer to us cannot be ſeen as a globular Body: But both *Sun* and *Moon* ſhew themſelves to us as if they were circular Planes, which we call Disks: And a Point in the middle, which is really in the Surface, is ſaid to be the Center, or the Apparent Center of the Disk. *The convexity of the* Sun *and* Moon *cannot be perceived by our Eyes.*

IF the *Sun* thro' all its Parts were every where equally bright, and ſhined with the ſame Luſtre, he might turn round his own *Axis*, and that Rotation no ways be perceptible, nor to be diſcovered by our Senſes. But ſince in the moſt clear and lucid Body of the *Sun*, and in its pureſt Flame, many black Spots have ſeveral times been obſerved, it is by their Motion that we diſcover the Rotation of the *Sun* round his *Axis*: For theſe Spots have been obſerved to have firſt appeared near the Margin of the *Sun*, and then by degrees to have crept towards the middle, or Center of his Disk; and from thence going ſtill forward have arrived at the oppoſite ſide or edge of the Disk, where they have Set or diſappeared; *Dark Spots on the* Sun's *Body.*

and

Lect. V. and ſome of them after ſetting, being hid or abſconded in the oppoſite ſide of the *Sun* for the ſpace of about fourteen Days, have again appeared in the Margin, and ſhewed themſelves, taking the ſame Courſe as before. Let the Circle AGHD repreſent the *Sun*'s Disk, we often obſerve ſome denſe and obſcure Subſtances, like our thick and Terreſtial Clouds, to appear in the Limb or edge at A, which by degrees move towards B, and at laſt arrive at the middle of the Disk; after which ſtill going forward, they ſhew themſelves in the oppoſite Point of the Circumference at D; where after a little ſtay, they at laſt vaniſh and diſappear.

Plate II. Fig. 4.

SOME of theſe Spots have been obſerved to Riſe in the Limb, and having traverſed the Disk and Set, after the ſpace of twenty ſeven Days, have again been ſeen to Riſe where they firſt appeared; and the time they take to move thro' the Surface of the *Sun* oppoſite to us, during which time they are inviſible, is juſt equal to the time in which they paſs over the viſible Disk. The Motion of theſe Spots in the Margin, at A or at D, appears to be ſlow; when they come towards the middle they ſeem to move quicker, and to deſcribe larger Spaces; their Figures likewiſe change, for in the Limb they are ſeen more contracted and narrow, near the Center they look broader and larger; theſe Appearances exactly anſwer to the Motion of ſome denſe and dark Bodies, which Swim upon the Surface of the *Sun*, and are whirled by the vertiginous Motion of the *Sun* round his *Axis*.

The Sun *turns round his* Axis.

SOME have imagined that theſe Spots do not ſtick upon the Body of the *Sun*, but that they are at ſome Diſtance from him, and that they perform their Circulations round the *Sun* in the ſame manner as *Jupiter*'s *Satellites* Circulate round *Jupiter*: But ſuch are eaſily refuted, for if the Spots were not on the Body of the *Sun*, but made their Circuits at a Diſtance from him, they could not be ſeen half the time of their Period

in

in the Body of the *Sun*; for ſuppoſe the *Sun* in A be ſeen from the *Earth* at B, under an Angle of 30 Minutes: If the Spot were not on the *Sun*'s Body, but deſcribed the Circle F E G at ſome Diſtance from him; it could not be obſerved to paſs under the *Sun* 'till it came to E, where the right Line B D touching the Diſk does cut the Orbit; and if we draw another Tangent to the Diſk B G C, it would only be ſeen on the Surface of the *Sun*, while it deſcribed the Arch E G, which is much leſs than half the Periphery, and is deſcribed in much leſs time than half the Period, in which the Spot performs its Circuit. Now we know by Obſervation that thoſe Spots which finiſh an intire Circulation (for ſome of them have been obſerved to make four or five compleat Revolutions before they were diſſolved, each of which was 27 Days) have taken $13\frac{1}{2}$ Days from the time of their appearing, or riſing on the *Eaſtern* Limb, to their Setting on the *Weſtern*: And therefore ſince the Spots are ſeen for half the time of their Period upon the Body of the *Sun*, it is plain their Orbits muſt lye on the *Sun*'s Surface.

Lect. V.

Plate II. Fig. 5.

The Spots are on the Surface of the Sun.

MANY Spots ſeem to be generated in the very middle of the Diſk, where they firſt begin to appear: Others again ſeem to be diſſolved and to vaniſh there; ſometimes ſeveral ſmall ones gather together and make a large Spot, and ſometimes a large Spot is ſeen to be divided, and cut into many leſſer ones. The Great *Italian* Philoſopher *Galileus*, firſt diſcovered them with his Teleſcope. Afterwards *Scheinerus* did more accurately obſerve them, who has publiſhed a large Volume about them. When he obſerved them, there were then 50 viſible in the *Sun*: From the Year 1650 to the Year 1670, there was rarely ſeen above one or two together; from that time again many have been obſerved together; nor does there ſeem to be any certain Period of Time, or Law for their appearing, and vaniſhing or diſſolution.

Spots generated in the Body of the Sun, *and again are there diſſolved or diſſipated.*

HISTO-

Lect. V. HISTORIANS tell us that the *Sun* has been obſerved for a whole Year to have appeared Pale, without that Luſtre and brightneſs it uſually gives; and that it hath not imparted its Heat and Light with the ſame Force and vigour that it ordinarily does. It is probable that this weakneſs of Light did ariſe from a great multitude of Spots which at that time did beſet the *Sun*, and covered a large Portion of his Surface: For now we frequently obſerve Spots which are larger or broader, not only than *Europe* or *Africk*, but what even equal, if they do not exceed, the Surface of the whole *Terraqueous* Globe.

The Sun has ſometimes appeared Pale for a Year together.

THE Motion of the Spots is from the *Weſt* to the *Eaſt*, and by obſerving the *Sun* nicely, we find that its *Axis* is not Perpendicular to the Plane of the *Earth*'s Orbit, which is called the Plane of the *Ecliptick*: But it is inclined ſo, as to make an Angle with the *Axis* of the Orbit, or with a Perpendicular to the Plane of the Orbit which paſſes thro' the Center of the *Sun*, which Angle is in quantity about ſeven Degrees: And therefore the Æquator of the *Sun*, that is to ſay, the Circle which is in the middle between the two Poles, cuts the Plane of the Orbit in a right Line, which Line produced will interſect the Orbit in two Points; and whenever the *Earth* comes to theſe two Interſections, the Tracts which the Spots deſcribe will appear as right Lines, ſince the Eye of the Spectator is in the Plane of their Motion: But in all other Poſitions of the *Earth*, the Plane of the *Sun*'s Æquator is either above or below the Eye of the Spectator, and the Lines in which the Spots are ſeen to move, appear crooked and ſeem to be *Ellipſes*.

The Axis of the Sun is inclined to the Plane of the Ecliptick.

SINCE the moſt bright Body of the *Sun* is not without its Spots and blemiſhes, we are not to imagine that the *Planets* are clear, and without their Stains and Marks. *Jupiter*, *Mars*, and *Venus*, when looked at thro' a Teleſcope, have ſeveral very remarkable ones; and it is by their Motions that we conclude the Rotation of the

The Planets likewiſe have Spots.

Planets

Planets round their *Axes*, after the ſame manner, and by the ſame Argument, that we proved the Rotation of the *Sun*. The Body of *Venus* performs its Revolution round its *Axis* in the ſpace of 23 Hours. *Mars* finiſhes his Rotation in 24 Hours and 40 Minutes. The *Earth* in a Day, which we collect from the Apparent Revolution of the Heavens and of all the *Stars* round it in that time. All theſe Bodies in their Rotations go the ſame way from the *Weſt* to the *Eaſt*.

They turn round their Axes.

JUPITER, beſides abundance of Spots, has ſome Bands or Girdles which ſurround him; they are Parallel to one another, but they neither preſerve the ſame Magnitude nor Diſtance; but ſometimes they encreaſe, ſometimes they diminiſh their breadth, ſometimes they approach each other, ſometimes they recede from one another, and undergo ſeveral Changes. In the Year 1665, M. *Caſſini* diſcovered a very large Spot in *Jupiter*'s Disk, which he obſerved continually for the ſpace of two Years, and determined accurately its Figure and Poſition in reſpect to his Girdles, but this Spot vaniſhed in the Year 1667, and was not again ſeen 'till the Year 1672: Afterwards for the ſpace of almoſt three Years it continually ſhowed it ſelf, and then by degrees withdrew it ſelf from our ſight, and has ſince ſeveral times appeared and diſappeared. In a Word, from the Year 1665 when it was firſt obſerved, to the Year 1708, it has eight times appeared and vaniſhed. By its Revolutions we conclude, that the Body of *Jupiter* moves round his *Axis* in the compaſs of nine Hours and 56 Minutes.

Jupiter's *Belts.*

The changes he undergoes.

IT is probable that our *Earth* enjoys a more conſtant and ſettled State and condition than *Jupiter*; for we obſerve greater Changes in his Surface, than what would happen to the *Earth*, if the *Ocean* ſhould leave its Place, and overwhelm the Land, and give us a new Place, and a new figure of the Sea, by changing the places of Land and Water. But this is upon Suppoſition that theſe Spots are inherent in the Body of

Lect. V. *Jupiter*: But if they are only Clouds and Vapours ſwimming in his Atmoſphere, then indeed the Inhabitants of *Jupiter* would have a more conſtant and permanent ſtate of Weather, than what any part of the *Earth* enjoys: I leave it to the *Philoſophers* to determine which of theſe two Opinions is the moſt probable.

MERCURY does always keep ſo near the *Sun*, with ſo great a ſhining Luſtre in all his Parts; and the Heaven, while he is ſeen, is ſo much Illuminated, that there can be no Obſervations made to diſcover his Spots. And *Saturn* is ſo much further removed from us, more than the other *Planets*, that his Spots are not to be diſcerned: Yet it is probable that they, as well as the other *Planets*, have each a Rotation round an *Axis*, that all the Parts of their Surfaces may frequently have imparted to them the Light and cheriſhing heat of the *Sun*, and may again be withdrawn from him, to receive ſuch Changes as are proper and convenient for the Nature of each *Planet*.

LEC-

LECTURE VI.

Of the Magnitude and Order of the fixed Stars. *Of the* Constellations, *Catalogues of the* Stars, *and the Changes to which they are liable.*

THE *fixed Stars* appear to be of different bigneſſes, not becauſe they really are ſo, but becauſe they are not all equally diſtant from us; thoſe that are neareſt will excell in Luſtre and Bigneſs; the more remote *Stars* will give a fainter Light, and appear ſmaller to the Eye. Hence ariſe the diſtribution of *Stars*, according to their Order and Dignity, into *Claſſes*; the firſt Claſs containing thoſe which are neareſt to us, are called *Stars* of the firſt Magnitude; thoſe that are next to them, are *Stars* of the ſecond Magnitude: The third Claſs comprehends them of the third Magnitude, and ſo forth, 'till we come to the *Stars* of the ſixth Magnitude, which comprehends the ſmalleſt *stars* that can be diſcerned with the bare Eye. For all the other *Stars* which are only ſeen by the help of a Teleſcope, and which are called Teleſcopical, are not reckoned among theſe ſix Orders. Altho' the diſtinction of *Stars* into ſix degrees of Magnitude, is commonly received by *Aſtronomers*; yet we are not to judge that every particular *Star* is exactly to be ranked according to a certain bigneſs, which is one of the Six; but rather in reality there are almoſt as many Orders of *Stars*, as there are *Stars*, few of them being exactly of the ſame Bigneſs and Luſtre. And even among thoſe

The diſtinction of Stars *according to their Magnitude.*

Lect. IV. those *Stars* which are reckoned of the brightest Class, there appears a variety of Magnitude, for *Sirius* or *Arcturus* are each of them brighter than *Aldebaran* or the *Bull*'s Eye, or even than the *Star* in *Spica*; and yet all these *Stars* are reckoned among the *Stars* of the first Order: And there are some *Stars* of such an intermedial Order, that the *Astronomers* have differed in Classing of them; some putting the same *Stars* in one Class, others in another. For Example: The little *Dog* was by *Tycho* placed among the *Stars* of the second Magnitude, which *Ptolemy* reckoned among the *Stars* of the first Class: And therefore it is not truly either of the first or second Order, but ought to be ranked in a Place between both.

The Constellations. *ASTRONOMERS* not only mark out the *Stars*, but that they may better bring them into Order, they distinguish them by their Situation and Position in respect to each other; and therefore they distribute and divide them into *Asterisms* or *Constellations*, allowing several *Stars* to make up one *Constellation*: A *Constellation* is a System of several *Stars* that are seen in the Heavens near to one another: And for the better distinguishing and observing them, they reduce the *Constellations* to the Forms of certain Animals, as *Men*, *Bulls*, and *Bears*, &c. or to the Images of some things known, as of a *Crown*, a *Harp*, a *Ballance*, *&c.* The Antients took these Figures from the Fables of their *Religion*: And the Modern *Astronomers* do still retain them, that they may avoid the Confusion which would arise by making new ones, which would much perplex them, when they compared the Modern Observations with the Old ones.

Their Antiquity. THE Division of the *Stars* by Images and Figures is of great Antiquity, and seems to be as old as *Astronomy*, or *Philosophy* its self: For in the most Antient Book of *Job*, *Orion*, *Arcturus*, and the *Pleiades*, are mentioned; and we meet with the Names of many of the *Constellations* in the

the Writings of the first Poets, *Homer* and *Hesiod*. For it was necessary for the Advancement of *Astronomy* so to distinguish the *Stars*, and to bring them into some Order. Lect. VI.

The same Face of the Starry Firmament *is observed from all the* Planets.

SINCE the Distance of the *Stars* is immensly great, it is no matter in what Place of our System the Observer resides, whether in the *Sun*, in the *Earth*, or even in *Saturn*, the outmost of all the *Planets*; for Spectators in each of those Places will see the same Face of the Heavens, the same *Stars*, with the same Magnitude, and the same Figure of the Constellations, and the Heavens which surrounds and involves them all, will have the same Face.

The Regions of the Heavens.

ASTRONOMERS divide the *Starry Firmament* into three Regions, the middle of which comprehends those *Stars* which have their Situation near the Planes of the Orbits in which the *Planets* move; this Part of Heaven they call the *Zodiack*, because the Constellations there placed, seemed for the most part to represent some *Animal* or living Creature. In this Space the *Planets* are always to be seen, and none of them ever transgress its Bounds: Upon each side of this *Zone* lye the other two Regions of the Heavens, one of which is called the *North*, and the other the *South* part of the Heavens.

The Images noted by the Antients are 48.

THE Antients divided the visible Firmament into XLVIII Images, twelve of which filled the *Zodiack*, and they give their Names to the twelve Signs, or the Portions into which it is divided. Their Names are the *Ram*, the *Bull*, the *Twins*, the *Crab*, the *Lyon*, the *Virgin*, the *Ballance*, the *Scorpion*, the *Archer*, the *Goat*, the *Water-Bearer*, and the *Fishes*.

IN the *Northern* Region there are XXI Images, *viz*. the *Lesser Bear*, the *Great Bear*, the *Dragon*, *Cepheus*, *Bootes*, the *Northern Crown*, *Hercules*, the *Harp*, the *Swan*, *Cassiopeia*, *Perseus*, *Andromeda*, the *Triangle*, *Auriga*, *Pegasus* or the *Flying-Horse*, *Equuleus*, the *Dolphin*, the *Arrow*, the *Eagle*, *Serpentarius*, and the *Serpent*: After-

Lect. VI. wards they added to them two others, *viz.* that of *Antinous*, which was made of the *Stars* that are not included within any Image, and are near the *Eagle*: And the Conſtellation called *Berenice's* Hair, conſiſting of *Stars* which are near the *Lyon's Tail.*

UPON the *South* ſide of the *Zodiack* there are fifteen *Aſteriſms*, which were known to the Antients, *viz.* the *Whale*, the *River Eridanus*, the *Hare*, *Orion*, the *Great Dog*, the *Leſſer Dog*, the *Ship Argo*, *Hydra*, the *Cup*, the *Crow*, the *Centaur*, the *Wolf*, the *Altar*, the *Southern Crown*, and the *Southern Fiſh*: To theſe are lately added XII more Conſtellations, which are not to be ſeen by us who Inhabit the *Northern* Regions, becauſe of the Convexity of the *Earth*; but in the *Southern* Parts they are very conſpicuous. Theſe are the *Phænix*, the *Crane*, the *Peacock*, the *Indian*, the *Bird of Paradiſe*, the *Southern Triangle*, the *Fly*, the *Chameleon*, the *Flying Fiſh*, the *Toucan* or *American Gooſe*, *Hydrus* or *Water Serpent*, *Xiphias* or the *Sword Fiſh.*

The Stars *without Forms.* WITHOUT the Compaſs of the Conſtellations or Images, there are ſeveral *Stars* which cannot be reduced to any of the Forms mentioned, and theſe are called *Unformed Stars*, out of which ſome great *Aſtronomers* have made new Conſtellations, as *Charles's Heart*, and *Sobieski's Shield.*

The Milky-way. THE *Galaxy* or *Milky-way*, is alſo to be reckoned among the Conſtellations: This is a broad Circle of a whitiſh Hue, like Milk; in ſome places it is double, but for the moſt Part it conſiſts of a ſingle Path, and goes round the whole Heavens. The Great *Galileus* with his Teleſcope, diſcovered that the Portion of the Heavens which this Circle paſſes thro', was every where filled with an infinite multitude of exceeding ſmall *Stars*, which tho' they cannot, by reaſon of their ſmalneſs, be ſeen diſtinctly by the naked Eye, yet with their Light they all combine to illuſtrate that Region of the Heavens where they are, and diffuſe thro' it a ſhining whiteneſs.

BY

BY the help of Images, the Antient *Astronomers* have been able to distinguish, and mark out the *Stars* of the Firmament, and with great Care and Industry they have digested them into Catalogues, which they have delivered down to Posterity. These Catalogues have been much increased and Corrected by our Modern *Astronomers*, and now they not only comprehend the *Stars* visible by the naked Eye, but also many that are not to be observed or seen without a Telescope. Lect. VI.

HIPPARCHUS the *Rhodian* about 120 Years before the Birth of *Christ*, was the First among the *Greeks* who reduced the *Stars* into a Catalogue. *Daring*, according to *Pliny*, *to undertake a Thing, which seemed to surpass the Power of a Divinity, that is to Number the* Stars *for Posterity, and reduce them to Rule; having contrived Instruments by which he marked the Place and Magnitude of each* Star. *So that by this Means we can easily discover, not only whither any of the* Stars *perish, and others grow up; but also whither they move, and what is their Course, and also if they grow bigger, or wax less; by which means he has given to Posterity the Possession of the Heavens, if any of them have Subtilty enough to Comprehend them.*

Hipparchus *first composed a Catalogue of the* Stars.

HIPPARCHUS from his own proper Observations, and those of the Antient *Astronomers* who lived before him, inserted into his Catalogue 1022 *Stars*, and annexed to each of them their proper Longitude, and Latitude, which they had at that time. *Ptolemy* enlarged *Hipparchus*'s Catalogue only with four *Stars*, numbring 1026. And after *Ptolemy*, *Ulug Beighi*, the Grandson of the Great *Tamerlain*, observed again the *Stars*, and reduced 1017 of them into a Catalogue. In the 16th Century, and that which followed, *Astronomy* was courted by many Admirers and Suiters; among whom we may chiefly reckon *Regiomontanus*, and *Copernicus*. But the Noble *Danish Astronomer Tycho Brahe*, in adorning

Ulug Beighi *made a new Catalogue.*

As likewise Tycho Brahe.

Lect. VI. dorning and perfecting this Science, did far ſurpaſs the Labours of all that went before him; who procured very large and exquiſitely well contrived Inſtruments for obſerving the Heavens, and particularly he determined the Places of 777 *fixed Stars*, and reduced them into a Catalogue, their Places being all Calculated from his own proper Obſervations. *Kepler* indeed in his *Rudolphin* Tables gives us a Catalogue of the *Stars*, he calls *Tychonick*, in which he has put down 1163 *Stars*; but all of them except the 777 obſerved by *Tycho*, were taken partly from *Ptolemy*, and partly from other Authors. For *Tycho* in his own Catalogue ſets down no *Star* which he had not obſerved himſelf, by his own Inſtruments, and Calculated the Place from his proper Obſervations.

The Prince of Heſs.

ABOUT the ſame Time with *Tycho* lived *William* Prince of *Heſs*, who likewiſe obſerved the *Stars*: He had two *Mathematicians* to aſſiſt him, *Rothmannus* and *Byrgius*, with whom, by thirty Years continued Labour, he computed the Places of 400 *Stars* all founded on their own Obſervations, and inſerted them in a Catalogue.

Ricciolus.

THE Jeſuite *Ricciolus* inriched the Catalogue of *Kepler* with 305 *Stars*, by which means their Number was increaſed to 1468; but this Catalogue was not founded on his own Obſervations, for he and his Companion *Grimaldi*, did not take the Places of above 101 *Stars* with their own Inſtruments; and he took all the reſt from *Tycho*, *Kepler*, and other Authors: But it is Surprizing that *Ricciolus* ſhould inſert in his Catalogue ſeveral *Stars* which were plainly viſible in *Tycho*'s time, and duly obſerved by him, but which in *Riccioli*'s Days had vaniſhed, and were not to be ſeen; and yet they are preſerved in his Catalogue, as if he himſelf had then obſerved them.

BARTSCHIUS in his Book about the four Foot Globe Publiſhed at *Strasburgh* in 1635 in 4*to*, tells us that *Bayerus* had deſcribed in his *Uranometria* the Places of 1725 *Stars*, and he alſo

also boasts that he himself had painted in his Globe 1762 *Stars*, but he does not tell us by whom, or in what Year, they were observed. Lect. VI.

THE *Stars* near the *Antarctick Pole*, not to be seen in our Climate, were first accurately observed by my Collegue Dr. *Edmund Halley*, who being animated with a great Love of this Siderial Science, undertook a long, and no less dangerous Voyage to the Island of St. *Helena*, that he might there take the Position of the *Stars* which are within the *Antarctick Circle*; and he Published a Catalogue of 373 of them, whose Places he adapted to the end of the Year 1677.

Dr. Halley *first exactly observed the* Southern Stars.

THE illustrious *John Hevelius* of *Dantzig*, a Man of prodigious Industry, and unwearied Diligence, being well furnished with very exact Instruments, and with all the Tools that are proper for an *Astronomer*; did again assault the *Stars* with his Instruments, and computed the Places of 1553 of them from his own proper Observations, and so he composed a new Catalogue which contained 1888, *viz.* 950 known to the Antients, and which were to be seen at *Dantzig*; 603 new ones which no one before had ever rightly observed, and to them he joined 335 others round the *Antarctick Pole*, taken out of Dr. *Halley*'s, Catalogue which lye always hid under the *Horizon* of *Dantzig*.

Hevelius.

BUT the largest and most compleat Catalogue of the *Stars*, is shortly to be expected from the Labours of that most excellent Observer Mr. *John Flamsteed*, late Royal Professor of *Astronomy* at *Greenwich*; the Number of *Stars* inserted in this Catalogue reach to 3000. And as *Hevelius* doubled by his Observations the Number of *Stars* observed by *Tycho*: So our *British Astronomer* has as far outdone *Hevelius*, having by his Observations doubled the *Stars* that were observed by him: We are so much indebted to this *Astronomer* for the increase of the Knowledge we have of the *Celestial Bodies*, that there is not the least *Star* in the Heavens to be seen, whose Place and Situation is not

Mr. Flamsteed *has made the most Copious and most exact Catalogue.*

Lect. VI. better known, than the Position of many Cities thro' which Travellers do daily pass. Nor is it any wonder that the *Astronomers* should take so much Pains, and so obstinately watch the *fixed Stars*, to determine their Places; for without the exact setling of their Positions and Places, they could never have found out the ways of the *Planets*, nor have described their Orbits: For it is upon the Observations of the *fixed Stars*, as upon immoveable Pillars, that the whole Science of *Astronomy* is erected, and by them it is sustained.

The Number of the Stars.

OF the 3000 *Stars* inserted in Mr. *Flamsteed's* Catalogue, there are many that cannot be seen without a Telescope, so that it is seldom that even a very good Eye can reckon more than 100 together in the Heavens: This will certainly surprise a great many Persons, for in the Winter, in a clear Night, without *Moon-shine*, at first sight they seem to be innumerable. But this Appearance is only a deception of our Sight, arising from their vehement and strong Twinkling or Scintillation, while we look upon them confusedly, and without reducing them to any Order; but he who will distinctly view them, will find not one but what are Observed by the *Astronomers*, and inserted in their Catalogues: And if any one will take a Globe of the larger size, and compare it with the Heavens, he will rarely find any *Star* in the Heavens, that is not marked upon the Surface of that Globe.

IN the mean time I must acknowledge that the Number of the *Stars* is really vastly great, and almost infinite; for whoever will view the *Stars* with a good Telescope, will find every where a prodigious Number of them altogether indiscernable by the naked Eye, especially in the *Milky-way*; where they are so thick, that tho' they cannot be seen separately, yet they give that Region of the Heavens where they are placed, a Lustre above all the rest.

THE

THE Famous Dr. *Hook* Professor of *Geometry* in *Gresham College*, directing his twelve-Foot Telescope to the *Pleiades* or the seven *Stars*, tho' there are now only but six to be seen with the naked Eye, did in that small compass count 78 *Stars*; and making use of longer and more perfect Telescopes, he discovered a great many more of very different Magnitudes: See his *Micrography*, pag. 241. *Antonius Maria de Reita* in his Book which he calls *Radius Sidereomysticus*, pag. 197 affirms, that he has numbered in the single Constellation of *Orion* 2000 *Stars*.

Many Stars imperceptible to the naked Eye.

FROM what we have said, in the preceding Lecture, it plainly appears, how false and ill founded, was the Notions of the Antient *Philosophers*, who having too favourable an Opinion of the Heavenly Regions, granted them some Priviledges without any reasonable ground: For they affirmed that the Heavens were incapable of any Change, that the Celestial matter was of a different kind from any we have in our *Earth*, and that its firmness did far exceed that of the most durable Diamond, for that is still Corruptible and may be changed into other sorts of Matter, and undergo several Transmutations: But the Form of the Heavenly matter, according to them, is permanent and Eternal. We have seen in the *Sun* and *Planets* that there are frequently new Bodies produced and generated; others again are corrupted and perish, and the Faces of the *Planets* undergo many Changes. Those *Alterations* are not peculiar to our *Earth*, or our Planetary System; the Principle of Generation and Corruption is much further diffused, it reaches even the most distant *fixed Stars*, and all the Bodies of the Universe are under its Dominion; there is nothing but our Mind and our Spiritual part that are exempted from its Jurisdiction: For the Heavenly Bodies as well as the Terrestrial are changeable and perish. Several *Stars* which were observed by the Antients, are now no more to be seen, but are destroyed, and we have known some new ones

The matter of the Heavens is corruptible and changeable.

Lect. VI. come in the Heavens unknown to them; which likewise in due time will vanish, and disappear: There are also some *Stars* which for a Time are extinguished, and become invisible, but after a certain Period they reassume their former Lustre. Of these *Stars* the most remarkable is that which is in the Neck of the *Whale*, which for eight or nine Months of the Year withdraws it self from our Sight, and for the other three or four Months is constantly changing its Lustre and Bigness. It is probable that the greatest Part of the Surface of this *Star* is covered with Spots and dark Bodies, some Part thereof remaining lucid; and while it turns about its *Axis*, does sometimes show its bright Part, sometimes it turns its dark side to us: But the very Spots themselves of this *Star* are liable to Changes, for it does not every Year appear with the same Lustre; sometimes it resembles a *Star* of the second Magnitude, in other Years it can scarcely be reckoned among *Stars* of the third Order; nor are the Times of its visiting us, always of the same duration; for in some Years after three Months it takes its leave of us, in others we enjoy its Light for the space of four Months; nor does its increase or decrease always answer the difference of Times.

Some Stars *vanish or perish, and again appear.*

MOREOVER we are assured from the Observations of *Astronomers*, that some *Stars* have been observed which never were before, and for a certain time they have distinguished them by their *superlative Lustre*; but afterwards decreasing, they by degrees vanished and were no more to be seen. One of these *Stars* being first seen and observed by *Hipparchus*, the chief of the *Astronomers* of the Antients, set him upon composing a Catalogue of the *fixed Stars*, that Posterity might by it learn whether any of the *Stars* perish, and others are produced afresh.

New Stars.

AFTER several Ages, another new *Star* appeared to *Tycho*, and the *Astronomers* that were Contemporary with him; which just like the new *Star* in *Hipparchus*'s time, induced him like-

wise

Plate II

fronting page 58

wiſe to make a new Catalogue of the *fixed Stars.* Lect. VI.
This *Star* made its Appearance in the Conſtellation *Caſſiopeia,* and was firſt obſerved about the middle of *November* 1572, and never changed its Place all the time it was viſible, which was for the ſpace of ſixteen Months: But yet by degrees it diminiſhed, and at laſt became inviſible. Its Magnitude exceeded that of *Sirius* or *Lyra,* which are the brighteſt of the *fixed Stars,* and even vied with *Venus* when ſhe is neareſt to us: So that ſometimes it could be ſeen in fair Day light, or Sun ſhine; but at laſt it continually loſt ſomething of its Splendor 'till it quite diſappeared, and it has never been ſeen ſince. *Leovicius,* from the Hiſtories of thoſe Times, tells us, that in the Time of the Emperor *Otho,* about the Year 945, a new *Star* appeared in *Caſſiopeia,* juſt ſuch a one as was ſeen in his Time in the Year 1572. And he brings us another Antient Obſervation, that there was likewiſe ſeen in the *Northern* Region of the Heavens, near the Conſtellation *Caſſiopeia,* in the Year 1264, an eminently bright *Star,* which kept it ſelf in the ſame Place, and had no proper Motion. It is probable that theſe two *Stars* might have been the ſame with that which was ſeen by *Tycho,* and that in about 150 Years the ſame *Star* may again make its Appearance.

IN the Year 1600 and the following, *Kepler* obſerved another new *Star* in the *Swan*'s Breaſt, which remained viſible for many Years; and in *Hevelius*'s time looked like a *Star* of the third Magnitude, but at laſt became inviſible from the Year 1660 'till the Year 1666, when it was again obſerved by *Hevelius* as a *Star* of the ſixth Magnitude, juſt in the ſame Place it was at firſt obſerved in; where it now appears.

WE are aſſured by the Catalogues of the *fixed Stars,* that many *Stars* have been obſerved by the Antients, and ſome even by *Tycho,* which are now become Inviſible, and particularly in the *Pleiades* or ſeven *Stars*; there was formerly count-

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Lect. VI. ed Seven, but now we can reckon but Six, and so it was in *Ovid*'s time, who in his third Book of the *Fasti* has this Verse

Quæ septem dici, sex tamen esse solent.

THE celebrated Mr. *Montanere*, Professor of *Mathematicks* of the University of *Bononia*, in his Letter written to the ROYAL SOCIETY dated *April* 30, 1670 has these Words. "There "are now wanting in the Heavens two *Stars* of "the second Magnitude, in the Stern of the Ship "*Argo*, and its Yard; *Bayerus* marked them with "the Letters β and γ. I and others observed "them in the Year 1664, upon the Occasion of "the Comet that appeared that Year: When "they disappeared first I know not, only I am "sure, that in the Year 1668, upon the 10th of "*April*, there was not the least glimpse of them "to be seen; and yet the rest about them, even "of the third and fourth Magnitudes, remained "the same. I have observed many more Changes "among the *fixed Stars*, even to the Number of a "Hundred, tho' none of them are so great as those "I have shewed.

IT is no ways improbable that these *Stars* lost their Brightness by a prodigious Number of Spots, which intirely covered and as it were overwhelmed them. In what dismal condition must their *Planets* remain, who have nothing but the dim and twinkling Rays of the *fixed Stars* to enlighten them.

LECTURE VII.

Of the Motion of the Earth *round the* Sun: *And also about her own* Axis, *whereby the Apparent Motion of the* Sun *and Heavens are explained.*

HAVING taken a Cursory view of the Universe, and explained those Things which we have discovered concerning the *fixed Stars*, we will now come to consider more accurately our own Solar System; for our *Astronomy* is chiefly concerned about the Motions of the Bodies that are contained in it, and about the Appearances or *Phænomena* that arise from those Motions.

We are to begin with the Motion of the Earth.

AND first it is reasonable that we should begin from the Motion of the *Earth*, which is our own Seat and Habitation, that is from our own Motion; since we are to be the Spectators of all the Appearances which are here to be explained, and particularly because from our Motion arises the Apparent Motion of the *Sun*, which if not first known, the Appearances and Motions of the *Planets* can neither be explained or computed.

The Sun *in the Center of our System.*

WE have in the preceding Lectures demonstrated that the *Sun*, which is by far the biggest and most noble Body of the Universe, does possess himself of the Center, from whence he every way diffuseth upon all the *Planets* his enlivening Beams and Warmth; and that they as it were Dance round him at different Distances and Periods. The *Earth* which we inhabit is to be reckoned as one of them, who goes round the *Sun* in the space of a Year; and at the same time

The Earth *turns round the* Sun.

Lecture VII.

time turns round her own *Axis* every twenty four Hours. Now ſince the Diſtance of the *fixed Stars* is immenſly great, in compariſon of the Diſtance of the *Earth* from the *Sun*, the Starry Firmament will have the ſame Face, and there will be the ſame Situation, Order, and Magnitude of the *Stars*, whether they be viewed from the *Sun*, or from the *Earth*: But ſince all diſtant Bodies appear as if they were in the Heavens, a Spectator in the *Sun* will obſerve the *Earth* to deſcribe a Circle in the Starry Firmament; and becauſe the Plane of the *Earth*'s Orbit paſſes thro' the *Sun*, the Circle which the *Earth* deſcribes will appear to be a great Circle in the Heavens.

The ſame Order and Poſition of the Stars *is ſeen from the* Sun *and* Earth.

The Motion of the Earth *ſeen from the* Sun.
Plate III. Fig. 1.

LET S repreſent the *Sun*, A B C D the Orbit of the *Earth*, in which the *Earth* is carried from the *Weſt* to the *Eaſt* in the compaſs of a Year. A Spectator in S looking upon the *Earth* at A, will referr it to the Star ♈, as if it were in the ſame point of Space with that *Star*: But when the *Earth* is brought to B, the Spectator in S will ſee the *Earth* in the Heavens juſt by the Star ♋; when the *Earth* is gone forward to C, it will be ſeen from the *Sun* in ♎; and when it is come to D, it will appear in ♑; and when it is returned to A, having finiſhed its Period, it will be ſeen again in ♈.

HENCE if the Plane of the *Earth*'s Orbit be imagined extended to the Heavens, as far as the *fixed Stars*, it will cut the Starry Firmament, or the concave ſpherical Surface, in which all the *Stars* appear, in that very Circle in which a Spectator in the *Sun* would ſee the *Earth* to revolve every Year: This Circle is called the *Ecliptick*, and is divided by the *Aſtronomers* into twelve equal Parts, which are called Signs; each of them takes its Name from that Conſtellation, which, at the time the Names were impoſed, was ſituated near the Portion of the *Ecliptick* it denominates. Theſe Signs or Portions are the *Ram* ♈, the *Bull* ♉, the *Twins* ♊, the *Crab* ♋, the *Lyon* ♌, the *Virgin* ♍, the *Ballance* ♎, the *Scor-*

The Ecliptick *and its Diviſion into 12 Parts or Signs.*

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pion ♏, the *Archer* ♐, the *Goat* ♑, the *Water Bearer* ♒, and the *Fishes* ♓.

Lecture VII.

The Apparent Motion of the Sun seen from the Earth.

LET us now bring our Spectator from the *Sun* to the *Earth*, and let him be carried by it round the *Sun*, and let us imagine that the *Earth* is in C: A Spectator sees the same Face of the Heavens, and the very same Constellations, as we have said he did before while he was in the *Sun*; the only difference will be, that as before he imagined the *Earth* in the Heavens, and the *Sun* in the Center, he will now suppose the *Sun* to be in the Heavens, and himself with the *Earth* in the Center, it being really the Center of his own view. Therefore the *Earth* being in C, the Spectator will see the *Sun* at the Star ♈; and the Spectator being carried along with the *Earth*, and participating of the Annual Motion, which is common to them both, he will observe all the Parts of the *Earth*, and all the Bodies fixed on its Surface to keep the same Position in regard to one another, and to his own Eye, and always to remain at the same Distance from him; and therefore he cannot by his Eye perceive either his own Motion, nor that of the *Earth*. But looking to the *Sun*, and observing him, when the *Earth* comes to D, he will see the *Sun* at the *Star* ♋, and will perceive that he has changed his Place among the *Stars*, and has moved from ♈, by ♉, ♊, to ♋: And while the *Earth* goes on in its Progress, and goes to A, the *Sun* will be seen from thence to have moved thro' the Signs ♋, ♌, and ♍: and Again, while the *Earth* describes the Semicircle A B C, the *Sun* will appear to have moved, in the concave Surface of the Heavens, thro' the six Signs ♎, ♏, ♐, ♑, ♒, ♓. And therefore an Inhabitant of the *Earth*, observes the *Sun*, which is really immoveable, to go thro' the same Circle in the Heavens, and in the same Space of time, that a Spectator in the *Sun* would see the *Earth* describe.

HENCE

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HENCE arises that Apparent Motion of the *Sun*, by which it is observed to creep every Day by little and little towards the *Eastern Stars*; so that if any *Star* near the Ecliptick does at any time rise with the *Sun*, after some few Days the *Sun* will be got more to the *East* of the *Star*, and the *Star* will rise before the *Sun*, and will likewise set before him. So likewise a *Star* which is *Eastward* of the *Sun* and is seen after the *Sun* sets, at a considerable Distance from him, in the Space of some few Days will set with the *Sun*, and will no more be seen, after the *Sun* goes down. This Motion of the *Sun* which is contrary to the apparent Diurnal Revolution of the Heavens from *East* to *West*, was esteemed to be real by the Followers of *Ptolemy*, who maintained that the *Sun* and all the *Stars* had two Motions, contrary to one another, the one common with the Heavens from *East* to *West*, in the Space of 24 Hours; the other proper, and peculiar to each, and was from the *West* to the *East*; which Course the *Sun* finished in the Space of a Year. But we have shewed that there is no such real Motion in the *Sun*, and that it is only Apparent, arising from the Motion of the *Earth*.

The Sun *will have just such Motions when it is observed from other* Planets.

THE Inhabitants of all the other *Planets* will observe just such Motions in the *Sun*, and for the very same reasons that we do in our *Earth*: And the *Sun* will be seen from every *Planet*, to describe the same Circle, and in the same space of Time, that a Spectator in the *Sun* would observe the *Planet* to do. For Example: An Inhabitant of *Jupiter* would think that the *Sun* turns round him, and would see him describe a Circle in the Heavens, in the space of twelve Years; that Circle would not be the same with our Ecliptick, and the Motion of the *Sun* would not be thro' the same *Stars*, which he appears to us to pass by. And upon the same Account the *Sun* seen from *Saturn* will appear to move in another Circle distinct from either of the former, and will not seem to finish his Period in less time than

than 30 Years. Since therefore it is impossible that the *Sun* can have all these Motions really in it self, and there can be no reason shewn why any one of them should belong really to the *Sun* more than the rest, we may safely affirm that there are none of them real, but that they are all Apparent, and arise from the Motions of the respective *Planets*. Lecture VII.

The Gyration of the Earth *round its* Axis.

BESIDES this Annual Circulation of the *Earth*, it has also a *vertiginous Motion* round his *Axis*, from the *West* to the *East*, in twenty four Hours: The two Points in which the *Axis* meets with the Surface of the *Earth* are called the *Poles* of the *Earth*, and if this *Axis* be indefinitely produced to the Heavens both ways, it will mark in the Heavens two Points, which are called the *Poles* of the Heavens: Every Point on the Surface of the *Earth*, except the *Poles* will describe the Circumference of a Circle bigger or less, according as it is further distant or nearer to one of the *Poles*. The *Poles* are the only two Points which have no Verticity: This plainly follows from the Nature of a Vertiginous Motion. Any place on the Surface of the *Earth*, which is equally distant from both the *Poles*, describes by its Rotation a great Circle, which is called the *Æquator* of the *Earth*, or the *Æquinoctial Circle*; and the rest described by Points nearer to one of the *Poles*, are lesser Circles and are called Parallels.

The Poles.

*The Æ*quator, *or* Æquinoctial *and Parallels.*

IF we imagine a Plane to pass over that Point of the *Earth*'s Surface on which the Spectator stands, and to touch the Globe of the *Earth* there; this Plane extended as far as the Heavens, will divide the Heavens into two Parts, and its Section with the Heavens will make a Circle, which is called the *Horizon*; and it will separate or distinguish the visible and open part of the Heavens, from that which is invisible, and which the Opakeness and Convexity of the Earth hides from us. This *Horizon* which we have described is properly the Sensible *Horizon*: The Rational *Hori-*

The Horizon.

Plate III. Fig. 2.

The Sensible and Rational Horizon.

Lecture VII.

zon being a diſtinct Circle, which paſſes thro' the Center of the *Earth*, and is Parallel to the ſenſible which touches the Surface. But theſe two Circles, tho' they are diſtant from one another by the Semidiameter of the *Earth*, yet in the Heavens they may be reckoned as coinciding, for that Semidiameter is but a Point, in compariſon of the Diſtance of the Heavens.

The Rotation of the Earth *produces an Apparent Revolution of the Heavens round the* Earth.

SINCE the *Earth* turns round its *Axis*, the Spectator ſtanding on its Surface, muſt likewiſe turn round with it the ſame way, that is towards the *Eaſt*: And therefore all the Bodies in the Heavens, which are placed in the *Eaſt*, and were not to be ſeen by reaſon the Plane of the *Horizon* was above them, will become Viſible, when by the Rotation this Plane ſubſides, and comes under them: So likewiſe the oppoſite part of this Plane towards the *Weſt*, riſing above the *Stars*, will hide them from the ſight of the Spectator, and all the *Stars* in the *Weſt* will become Inviſible: Hence it is the *Stars* of the *Eaſtern* ſide of the *Horizon* will appear to riſe above the *Horizon*, becauſe the *Horizon* deſcends below them, and the *Stars* on the *Weſtern* ſide will appear to ſet or go below the *Horizon*, becauſe the *Horizon* does really get above them. Hence ariſes that Apparent Motion of all the Bodies of the Univerſe that do not adhere to the *Earth*, wherewith the whole Starry Firmament, and every Point of the Heavens ſeems to revolve about the *Earth* from *Eaſt* to *Weſt*; every Point deſcribing a greater or a leſſer Circle, as it is more remote or nearer to one of the Celeſtial *Poles*: And theſe Celeſtial *Poles* which are made by the Production of the *Earth*'s *Axis* to the Heavens, are the only Points in the Heavens, which appear to be immoveable.

ALTHO' every place on the Surface of the Terraqueous Globe, is illuſtrated by all the *Stars* which are above the *Horizon* of that Place, or rather when the *Horizon* is under the *Stars*; yet the Illumination made by the *Sun* is ſo great,

and

and the Reflection of its Light by the Atmosphere so strong, that the *Sun* when he is above the *Horizon*, does with his Presence quite extinguish the faint Light of the *fixed Stars*, and produces Day: When the *Sun* withdraws himself and goes below our *Horizon*, or more properly when our *Horizon* gets above the *Sun*, he then gives leave to the *Stars* to Shine and appear, at which time it is Night. Now since the *Earth* is an opake Spherical Body, at a great Distance from the *Sun*, one half of it will always be illuminated by the *Sun*, while the other half remains in Darkness: And the Circle which distinguishes the illuminated Face of the *Earth* from the Dark side, is called the Circle of the Intersection of Light and Shadow; a Line drawn from the Center of the *Sun*, to the Center of the *Earth*, is always Perpendicular to the Plane of this Circle.

Lecture VII.

Whence Day-Light.

Whence Night.

The Circle bounding Light and Darkness.

IF the *Axis* of the *Earth* had been placed in a Position Perpendicular to the Plane of the Ecliptick, then in that case the Plane of the *Earth*'s Æquator had coincided with the Plane of the Ecliptick, or the Plane of the *Earth*'s Orbit; and the Circle bounding Light and Darkness, would have always passed thro' the *Poles* of the *Earth*, and cut the Æquator and all its Parallels into equal Portions: And therefore in that case, the *Sun* and all the *Stars* would have remained as long above the *Horizon*, as they would have lain hid under it, and the Days would have been constantly equal to the Nights. But now, as the Case is, the *Axis* of the *Earth* is not Perpendicular to the Plane of the Ecliptick, but is inclined to that Plane, and makes with it an Angle of $66\frac{1}{2}$ Degrees; and therefore the Plane of the *Earth*'s Æquator cannot coincide with the Plane of the *Ecliptick*, but these two Planes make with one another an Angle of $23\frac{1}{2}$ Degrees.

The Axis of the Earth *is not Perpendicular to the Plane of the Ecliptick.*

IF the Plane of the *Earth*'s Æquator be imagined to be produced as far as the *fixed Stars*, it will there make a Circle which is called the Celestial Æquinoctial; which is exactly over the

The Æquinoctial of the Heavens.

 Terre-

Lecture VII. Terrestial Æquinoctial: This Circle makes with the Ecliptick in the Heavens, an Angle likewise of $23\frac{1}{2}$ Degrees.

The Parallelism of the Earth's Axis.

THE *Earth* in its Revolution round the *Sun* does in such a manner proceed in its Orbit, that it keeps its *Axis* Parallel to it self; that is, if a Line be drawn Parallel to the *Axis* while it is in any one Position, the *Axis* in all other Positions or Parts of the Orbit will always be Parallel to that same Line, and it will never change its Direction, but always look towards the same Point of the Heavens: And this will necessarily be, if the *Earth* have no other Motion but that round the *Sun*, and the other round its own *Axis*. For suppose any Body, whose Center is carried in the Line A B, and in A we should Mark any Diameter C D, which is inclined in any Angle to the Line A B; if this Body have no other but a progressive Motion in the Line A B, when it comes to the Point B, the Diameter C D will be in the Situation *c d*, and its Position will be Parallel to the former Position C D: Now if there should be impressed upon this Body a Rotation round C D as an *Axis*, all the Diameters of the Body will constantly change their Position by this Rotation, except the *Axis* which will remain is its former State: The Points in the *Axis* being the only Points in the Body which have no Rotation: But this *Axis*, as was shewed, did before the Rotation always preserve a Position Parallel to it self, therefore after the Rotation is impressed upon the Body, the *Axis* will still keep Parallel to its self.

Plate III. Fig. 3.

HENCE it is evident that there is no need of a third Motion for the *Earth*, as some have imagined it must have, to make it keep its *Axis* Parallel to its self: For to this effect there is nothing more required, that than it should have only the former two, with which alone it will necessarily keep its *Axis* Parallel to it self.

SINCE

SINCE the Plane of the Æquator does not coincide with the Plane of the Ecliptick, these two Planes must cut one another in a right Line, and while the *Earth* turns round the *Sun*, the common Section of these two Planes will likewise always remain Parallel to its self; for the same reason as we shewed in the Position of the *Earth's Axis*: And therefore this Section or Line, in which the Planes cut one another, will always be directed towards two opposite Points of the Ecliptick, and will always look to the same Points of the Universe.

Lecture VII.

A great Circle in the Heavens passing thro' the two Celestial *Poles*, and the common Section of the Æquator and the Ecliptick is called the *Æquinoctial Colure*: An other Circle cutting the former in the *Poles* at right Angles, is called the *Solstitial Colure*, which passes thro' the Points where the Æquator and Ecliptick are at the greatest Distance from one another, and cuts likewise both these Circles at right Angles, and therefore does likewise pass thro' the *Poles* of the Ecliptick, or that Point which is every where equally distant from the Ecliptick. The four Points in which these two *Colures* intersect the Ecliptick, are called the four *Cardinal Points*, because when the *Sun* is seen in them, he determines the four Seasons of the Year. The two Intersections of the *Æquinoctial Colure* with the Ecliptick, are called the *Æquinoctial Points*; the other two being the Intersections of the *Solstitial Colure* with the Ecliptick, are called the *Solstitial Points*.

The Æquinoctial Colure. *And the* Solstitial Colure.

The Cardinal Points.

SUPPOSE now the Eye of a Spectator to look from afar, obliquely upon the Orbit of the *Earth*; it will then appear or have a Representation of an Oval figure, according to the Rules of Perspective, and in the middle of this Oval the *Sun* will keep. Thro' the Center of the *Sun* S, draw the right Line ♈ S ♎ parallel to the common Section of the Æquator and the Ecliptick, which will meet with the Ecliptick in two Points ♈, ♎: And when the *Earth* seen from the *Sun* is in either

Plate III. Fig. 4.

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Lecture VII.

The different illumination of the Parallels, according to the Place of the Earth *in the* Ecliptick.

of these Points, the right Line S ♈ or S ♎, which joins the Center of the *Earth* and *Sun*, will coincide with the common Section of the Æquator and Eclipticks, and will then be Perpendicular to the *Axis* of the *Earth* or of the Æquator, because it is in the Plane of the Æquator: But the same Line is also Perpendicular to the Circle which bounds the Light and Darkness, and therefore the *Axis* of the *Earth* will be in the Plane of that Circle, which will therefore pass thro' the *Poles* of the *Earth*, and will cut the Æquator and all its Parallels into equal Parts. When the *Earth* therefore is in the beginning of ♎, the *Sun* will be seen in ♈, in the common Section of the Æquator and the Ecliptick; and therefore it will appear in the Celestial Æquinoctial, and will not be seen to decline to either of the *Poles*; but being exactly in the middle between both, it will then by its Apparent diurnal Revolution describe the Celestial Æquinoctial. In this Position of the *Earth*, the *Sun* will exactly illuminate the *Earth* from *Pole* to *Pole*, and as we said the Circle bounding Light and Darkness, will cut the Parallels exactly into equal Parts, and every Point of the *Earth* being carried round by the vertiginous Motion, will remain as long in the obscure side, as it was in the light or illuminated Portion of the *Earth*'s Surface: And therefore at that time thro' the whole Globe of the *Earth*, the Day will be equal to the Night: From hence the Circle which that Day the *Sun* seems to describe in the Heavens, has obtained the Name of *Æquinoctial*.

The Appearances when the Earth *is in* Libra, *and the* Sun *is seen in* Aries.

The Appearances when the Earth *is in* Capricorn.

THE *Earth* in its Annual Motion going by degrees thro' ♏ and ♐ towards ♑, and the common Section of the Æquator and the Ecliptick remaining always Parallel to its self, it will no longer pass thro' the Body of the *Sun*, but in ♑ it makes a right Angle with the Line S P, which joins the Centers of the *Sun* and *Earth*: And because the Line S P is not in the Plane of the Æquator, but in that of the Ecliptick; the Angle B P S, which

which the *Axis* of the *Earth* makes with it, will not now be a Right Angle, but Oblique; these two Lines making an Angle of 66½ Degrees, which is the same with the Inclination of the *Axis* to the Plane of the Eclipticк. Let the Angle S P L be a Right Angle, and the Circle bounding Light and Darkness will pass thro' the Point L; and then the Arch B L, or the Angle B P L, will be 23½ Degrees, that is equal to the Complement of the Angle B P S to a right Angle.

Lecture VII.

LET the Angle BPE be a right Angle, and then the Line P E will be in the Plane of the Æquator: Therefore because the Arches BE and LT are equal, each of them being Quadrants; if the common Arch B T be taken away, there will remain T E equal to L B equal to 23½ Degrees. Take E M equal to E T, and thro' the Points M and T, describe two Parallel Circles T C, M N; the one is called the *Tropick* of *Cancer* ♋, the other the *Tropick* of *Capricorn* ♑. And the *Earth* being in this Situation, the *Sun* will shine perpendicularly upon the Point T, and then it will seem to approach the nearest that it can come to the *North Pole*. And the Circle which, by the Apparent diurnal Revolution of the Heavens, the *Sun* seems to describe, will be directly over the Circle T C in the *Earth*, which Circle is therefore called the Celestial Tropick of *Cancer*: Now upon the account of the Revolution of the *Earth* round its *fixed Axis*, all the Points of the Parallel T C will in their turns pass by the Point T, and will be directly under the *Sun*; and therefore the *Sun* will be vertical to all the Inhabitants that are under the Tropick of ♋, when he comes to their Meridians. While the *Earth* is in this Position, it is manifest that the Circle which bounds Light and Darkness reaches beyond the *North Pole* B to L; but towards the *South* it falls short of the *South Pole* A, and reaches no further than F. Thro' L and F let two Parallels to the Æquator be

The two Tropicks.

 described,

Lecture VII. described: These two Circles are called the *Polar Circles*; this is called the *Arctick Polar*, the other the *Antarctick*. And while the *Earth* is in P, all that Tract of it which is included within the *Polar* Circle K L continues in the Light, notwithstanding the constant Revolution round the *Axis*; and the Inhabitants there enjoy a continual Day. On the contrary those that lye within the *Antarctick* Circle remain in continual Darkness, having all Night without any Day. Besides it is likewise manifest, that all the Parallels between the Æquator and the *Arctick* Circle, are cut, by the Circle bounding Light and Darkness, into unequal Portions; the largest Portions of these Circles remaining in the Light, and the smallest in Darkness: But those Parallels which are towards the *Antarctick* Circle have their greatest Portions in Darkness, and their least in the Light; and the difference of these Portions will be greater or less, according as the Circles are nearer to the *Pole* or to the Æquator. Therefore in this Position of the *Earth*, when the *Sun* is seen in ♋, the Inhabitants of the *Northern Hemisphere* will have their Days at the Longest, and their Nights the Shortest; and the Season of the Year will be Summer. But in the *Southern Hemisphere* the Inhabitants will have their Nights longest, and their Days shortest; and they will be in their Winter Season.

The Arctick and Antarctick Circles,

When the Days are Longest. When Shortest.

AND in every Place the length of the longest Days will be the greatest, and the Nights the shortest, according as the Place is further removed from the Æquator, and comes nearer the *North Pole*. We see likewise that, of all the Parallels, there is only the Æquator which is cut into equal Parts by the Circle bounding Light and Darkness, they being both of them great Circles: And therefore it is only the Inhabitants of the *Earth* that live in the Æquator, that have their Days constantly equal to their Nights, throughout the whole Year.

WHILE

WHILE the *Earth* goes on from ♑ by ♒, ♓ to ♈, in which time the *Sun* is ſeen to paſs thro' the Signs ♋, ♌ and ♍, he will appear to return by little and little towards the Æquator; and when the *Earth* is arrived at ♈, the *Sun* will appear in ♎, where the common Section of the Æquator and the Ecliptick always keeping Parallel to its ſelf, will paſs thro' the Center of the *Sun*, and then the *Sun* will appear in the Celeſtial Æquinoctial: At which time the Days will again be equal to the Nights, to all the Inhabitants of the *Earth*; juſt after the ſame way as it was when the *Earth* was in ♎, in that Poſition the Circle bounding Light and Darkneſs paſſing thro' the *Poles*.

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The Appearances when the Earth *is in* Aries.

THE *Earth* moving on thro' ♈, ♉ and ♊, the *Sun* will be ſeen to go in the Ecliptick thro' ♎, ♏ and ♐, and will appear to decline from the Æquator towards the *South*; ſo that when the *Earth* is really in ♋, the *Sun* will appear among the *Stars* near the Conſtellation ♑. And whereas the *Axis* B A does not change its Inclination, but does always retain its Parallelism, the *Earth* will have the ſame Aſpect and Poſition in reſpect to the *Sun*, that it had when it was in ♑; but with this difference, that when the Tract within the *Polar* Circle K L was in continual Light while the *Earth* was in ♑; now the *Earth* arriving at ♋, that ſame Tract will be altogether in Darkneſs, and the Beams of the *Sun* can not reach it. But the oppoſite Space within the Circle F G, will be in a continual illumination, and at the *Pole* A there will be no Night for the ſpace of ſix Months.

The Appearances when the Earth *is in* Cancer.

HERE likewiſe of the Parallels between the Æquator and the *North Pole*, the illuminated Portions are much leſs than the Portions which remain in Darkneſs; the contrary of which happened in the former Poſition, ſo likewiſe the *Sun* at mid-day will appear vertical,

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or directly over Head to all the Inhabitants that live in the Tropick M N, ſo that it will appear to have deſcended towards the *South* from the Parallel T C to the Parallel M N, thro' the Arch C Q N, which is 47 Degrees. Therefore the Inhabitants of all Places of the *Earth* that are beyond the Tropicks, towards either of the *Poles*, have the *Sun* in their Summer 47 whole Degrees nearer to their Vertex or to the Point directly over their Heads, than in the oppoſite time of Winter. This change of Situation in reſpect to the *Sun*, does not ariſe becauſe the *Earth* is raiſed or depreſſed, but on the contrary, becauſe it is no where depreſſed and no where raiſed: But with its *Axis* keeps the ſame immutable Poſition, in reſpect of the Univerſe, only going round the *Sun* which is placed in the Center of its orbit, and the *Axis* thereof retaining the ſame Inclination to the Plane of the Orbit, and the ſame Situation in reſpect to any other fixed Line.

How all theſe Appearances may be repreſented to the Eye.

ALL we have here ſaid will appear evident to our Eyes, if we light a Candle in a dark Room, and take a ſmall Globe of two or three Inches Diameter, in which we muſt mark the *Poles*, the Æquator, ſome Parallels, and ſome Meridians, or Circles paſſing from *Pole* to *Pole*: Then we muſt ſo hold this Globe before the Candle, that its *Axis* may not be Perpendicular to the Plane of the Table on which the Candle ſtands, but let it be inclined to it, in an Angle nearly of $66\frac{1}{2}$ Degrees; then place the Globe in ſuch a manner, that one of its *Poles* may point directly *Northward*, and let the light of the Candle firſt reach from *Pole* to *Pole*, that is, let the Circle bounding Light and Shadow firſt paſs thro' the two *Poles* of the Globe: Then let the Poſition of the *Axis* be well obſerved, and then move the Globe round the Candle with your Hand, in a Circle Parallel to the *Horizon*, holding it ſo that

that the *Axis* may always point the ſame way, and retain the ſame Inclination to the *Horizon*. This done you will ſee that the Flame of the Candle will in the ſame manner illuminate this Globe, as the *Sun* actually does the *Earth*: And the *Poles* of the Globe, its Æquator and Parallels, will undergo the ſame viciſſitudes of Light and Darkneſs, which we have now explained.

The like Appearances from any other Planet *that turns round its* Axis.

THE like *Phænomena* or Appearances may be obſerved from any other *Planet* that turns round its *Axis*. For Example: *Jupiter* performs his Gyration in the ſpace of ten Hours; and therefore a *Jovian* or an Inhabitant of *Jupiter*, will ſee the whole Heavens, and even our *Earth* together with the *Sun*, to have a rapid Motion round his Body in the ſpace of ten Hours: But the *Axis* of *Jupiter* is very nearly Perpendicular to the Plane of his Orbit, and therefore the Circle bounding Light and Darkneſs in *Jupiter*, does always nearly paſs thro' his *Poles*; and therefore the Days and Nights in that *Planet* are almoſt conſtantly equal; hence it ſeems the *Jovians* enjoy an Uniform temperate Seaſon, without being uneaſy at the approaching Heats of the Summer or the Colds of the Winter.

The Axis *of the Ecliptick.*

IF thro' the Center of the *Sun* or *Earth* (it is no matter which, for theſe two Points at the Diſtance of the *Stars* will be ſeen to coincide) there be raiſed a Line which is Perpendicular to the Plane of the Ecliptick, and this Line be produced to the Heavens, it is called the *Axis* of the Ecliptick; and the two Points which this Line on both ſides produced does tend to in the Heavens, are called the *Poles* of the Heavens. Now if we imagine great Circles to paſs thro' theſe *Poles* and by every *Star* or *Planet*, they will all be Perpendicular to the Plane of the Ecliptick. Theſe Circles are called *Secondaries* of the *Ecliptick*, or *Circles* of *Latitude*. And an Arch of one of

The Secondaries of the Ecliptick.

theſe

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these Circles intercepted between any *Star* and the Ecliptick is called the *Latitude* of that *Star*, or its Distance from the Ecliptick; which may be either *North* or *South*, according as the *Star* is upon the *North* or *South* side of the Ecliptick. So also an Arch of the Ecliptick between the first Point of ♈, or its intersection there with the Æquator, and the Point where the Circle of Latitude passing thro' a *Star* cuts the Ecliptick, is called the *Longitude* of that *Star*.

The Latitude of a Star.

The Longitude of a Star.

AFTER the same manner if there be conceived innumerable Circles to pass thro' the two *Poles* of the *Earth*, and thro' each place on its Surface, they will all be Perpendicular to the Æquator, and they are called Secondaries of the Æquator: But in respect of the Places thro' which they pass, they are called *Meridians*, because when the *Sun* is seen in any place in the Plane of such Circle, it will be mid-day to the Inhabitants of that Place. The Arch of one of these Secondaries intercepted between any place and the Æquator, is called the *Latitude* of the Place; or its Distance from the Æquator, which may be likewise either *North* or *South*: And that Arch of the Æquator, that lies between the Interfection of the Secondary passing through any Place, with the Æquator, and any other fixed Point in the Æquator, is called the *Longitude* of that Place.

The Meridians.

The Latitude of a Place.

Its Longitude.

LEC-

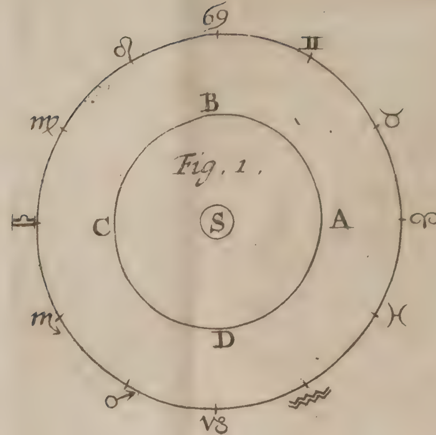


Fig. 1.
B
C
S
A
D

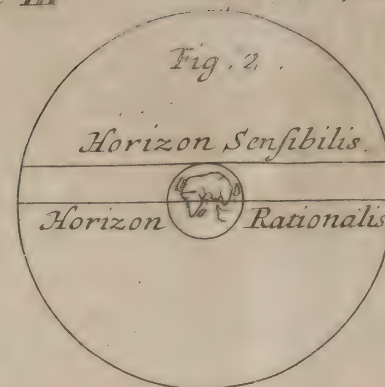
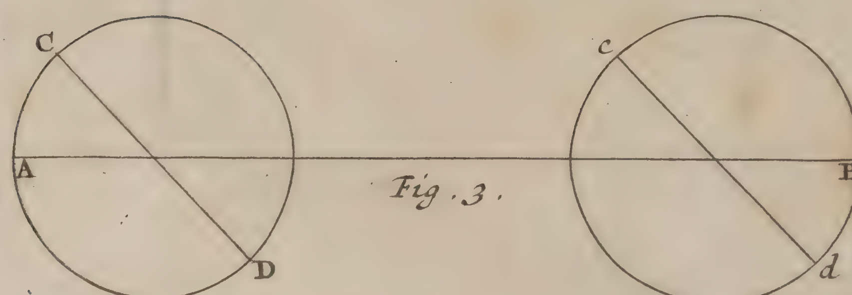
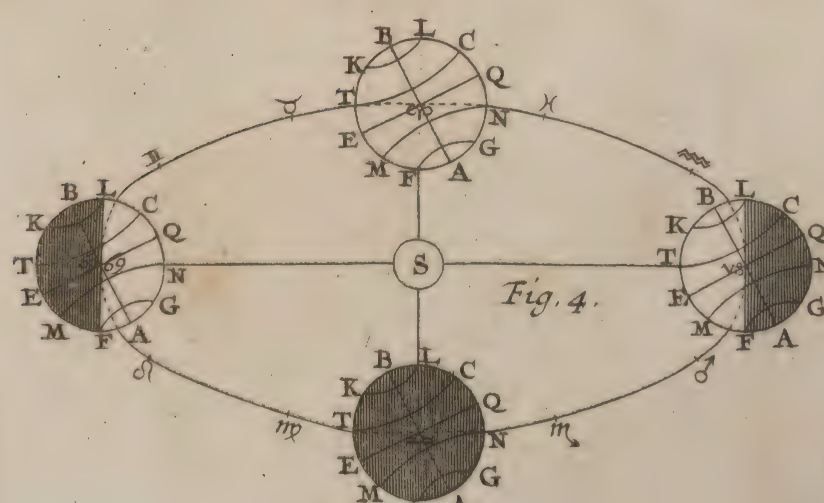


Fig. 2.
Horizon Senſibilis.
Horizon
Rationalis


C
A
D
c
B
d
Fig. 3.


B L C
K
Q
T
N
E
G
M F A
S
Fig. 4.

LECTURE VIII.

Concerning several other Phænomena *or Appearences, which depend on the Motion of the* Earth.

SINCE the *Earth* turns so round the *Sun* that its *Axis* always remains Parallel to it self, it seems necessary that this *Axis*, at different Seasons of the Year, should point to different *fixed Stars*, and that the *Star* or Point of the Heavens, which is directly over the *Pole* of the *Earth* in the Summer, should not be so directly over it in the Winter; but that the *Axis* should point to another *Star*, whose distance from the former should be equal to the whole Diameter of the *Earth*'s Orbit.

The Axis *of the* Earth *ought to point to different* Stars *at different times of the Year.*

FOR let ACBD be the Orbit of the *Earth*, in whose Center is the *Sun* S; A B the Diameter of the Orbit: When the *Earth* is at A, its *Axis* is directed to a *Star* E, which is directly over the *Pole* of the *Earth*: Now when the *Earth* comes to the opposite Point of the Orbit B, the *Axis* being in a Position Parallel to its former Position, it will no longer point to the *Star* E, but to another *Star* F, which two *Stars* will be distant from each other, the whole length of the Diameter of the great Orbit. But the Angular or observable distance of the *Stars* is the Angle E B F, which is equal to the Angle A E B, by the 29th Prop. 1st. Book of *Euclide*. But the Angle A E B is the Angle under which the Diameter of the great Orbit or Orbit of the *Earth* is seen from the *Star* E, which Angle E B F or A E B is called the *Parallax of the*

Plate IV. Fig. 1.

The Parallax of the great Orbit.

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the great Orbit, and if it could be obſerved, we might by it find the diſtance of the *Star* E from the *Earth*, in reſpect of the *Sun*'s diſtance from us. For in the Triangle E A B, we have the Angle E which is equal to the Angle E B F, which we ſuppoſe we can obſerve; we have likewiſe the Angle E A B, which in the *Equinoctial points* is always a Right Angle; and in the *Solſtices* it is equal to the Inclination of the *Earth*'s *Axis* to the Plane of the Ecliptick, and is always equal to the Viſible diſtance of the *Sun* from the *Pole*: Hence in this Triangle we have all the Angles; we have likewiſe the ſide A B, and conſequently by *Trigonometry* we can find the ſide A E, or EB, the diſtance of the *Star* E from the *Earth*.

This Parallax ſcarcely to be obſerved.

BUT the Truth is, that the diſtance of the *Stars* is ſo great in reſpect of A B, and the Angle E B F is ſo very ſmall, that there can be no Inſtruments made nice enough to obſerve it exactly; and they who have taken moſt Pains to find it out, could never obſerve it to be ſo great as one Minute: And ſince in the Obſervations of ſuch ſmall Angles, Errors are ſcarcely to be avoided, and ſuch too as will in the Computation produce prodigious differences in the diſtances which depend upon them; we cannot ſafely truſt ſuch Obſervations: For if with Mr. *Flamſteed* we ſhould ſuppoſe the Parallax, or the Angle E B F, to be 42 Seconds, and there be an Error committed in Obſervation, which makes the Angle 25 Seconds greater than it really is, (and no Man can be ſure that he has not committed ſuch an Error) the diſtance of the *fixed Stars* in that caſe will really be double of what our Obſervation makes it. But if the Obſervations happen to be leſs accurate, ſo that there may be a Minute or more between them and the Truth, (and moſt of our Obſervations are ſuch) the diſtance that ariſe from the Computations made on ſuch Obſervations, will be prodigiouſly wide of one another, and all of them very different from the Truth.

The Diſtance of the Stars uncertain.

HITHER-

Lecture VIII.

The Axis of the Earth does not preserve an exact Parallelism.

HITHERTO we have supposed the *Axis* of the *Earth* to have remained in an immutable Position, and to have continued in an exact Parallelism, and that the *Earth* had only two Motions, one Annual round the *Sun*, the other Diurnal round its *Axis*. But the *Astronomers*, from the Observations of many Years, have found that the *Axis* of the *Earth* has not exactly kept its Parallelism, but has deviated a little from that Position, so that tho' the Variation in the space of two or three Years be scarcely sensible, yet in many Years, or in a Century or two, it is very observable: And therefore while we were explaining the Appearences of one Year, we spoke nothing of this *Aberration*, for that could no ways disturb the *Phænomena* that were then to be explained; yet in the compass of several Years, this mutation or change of the Position of the *Earth*'s *Axis* becomes very remarkable. So the Direction of the *Axis* has been sensibly changed, tho' its Inclination to the Plane of the Ecliptick has remained the same, and from hence we find, that the *Axis* of the *Earth* has another Motion which is here to be explained.

Plate IV. Fig. 2.

Let the Line D C H represent a Portion of the *Earth*'s Orbit, and let the Center of the *Earth* be C; from which erect C E perpendicular to the Plane of the Ecliptick, meeting with the Concave surface of the Heavens in E: This Line C E will be the *Axis* of the Ecliptick, and E the *Pole* of it. Let C P be the *Axis* of the *Earth* produced to the Heavens, P will be the *Pole* round which the Heavens have an apparent diurnal Revolution. Thro' the two Points E and P draw a great Circle E P A, which passing thro' the *Poles* of both the Ecliptick and Æquator will be Perpendicular to both those Circles. Let it meet with the Ecliptick in A; the Arch P A will measure the Angle P C H, which is the Inclination of the *Axis* of the *Earth* to the Plane of the Ecliptick, that is, it will be $66\frac{1}{2}$ Degrees; and therefore the Arch E P which is its complement to a

The Axis of the Ecliptick.

Quadrant,

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Quadrant, will be $23\frac{1}{2}$ Degrees; which Arch will measure the Angle E C P, that the *Axis* of the Ecliptick and the Æquator make with one another. From the *Pole* E describe thro' P a lesser Circle P F G, which will be Parallel to the Ecliptick; and since the *Axis* of the *Earth* always keeps the same invariable Angle with the *Axis* of the Ecliptick, it will always be directed to some Point in the Periphery P F G, and the *Pole* of the World must always be somewhere placed in it: So likewise if the *Axis* of the *Earth* retained the same direction without any change, as often as the *Earth* came to the Point of its Orbit C, the Pole of the Heavens would be constantly in the indivisible Point P: But we find that the *Pole* of the World does constantly change its place in the Periphery P F G, and the *Axis* of the *Earth* which before pointed to P, after 72 Years will look to another Point Q, which is one Degree from P towards the *West*. And by this means the *Axis* of the *Earth*, or of the World, is carried in a *Conical Motion*, or describes the Surface of a *Cone*, whose Vertex is in the Center of the *Earth*, and its *Base* is the Circle P F G; and the *Pole* P will constantly move in the Periphery P F G, with a very slow and retrograd Motion, from the *East* to the *West*, and does not finish its Circulation in less than 25920 Years, after which time the *Pole* having left the *Star* at P, does again return thither. Hence it follows, that the *Star* which is now the *Polar*, and directly over the *Pole* of the *Earth*, after 12960 Years, which is half the Period of the *Polar* Revolution, will be 47 Degrees distant from the Pole, which will then be directed to G.

The Pole of the World moves backward in a lesser Circle Parallel to the Ecliptick.

The Circle E P A being Perpendicular to both the Ecliptick and the Æquator, will be the *Solstitial Colure*, and A will be the *Solstitial Point*, which Point of the Ecliptick is most distant from the Æquator: Now after the *Axis* of the *Earth* produced comes into the Position C Q, if there be drawn thro' the Poles of the Ecliptick

The Solstitial Colure.

Ecliptick and the Æquator the Circle E Q B, this Circle will then be Perpendicular to both Æquator and Ecliptick, and therefore when the *Axis* of the *Earth* is in the Position C Q, the Circle E Q B will be the *Solstitial Colure*, and the *Solstitial* Point will be B, where that Circle intersects the Ecliptick; and therefore the *Solstitial* Points will move backwards equally with the *Poles*; the Motion of the *Pole* being in the Circle P Q G which is Parallel to the Ecliptick, the Arches P Q and A B will be like or similar; so that when P Q is an Arch of one Degree, A B will likewise be an Arch of one Degree.

Lecture VIII.

The Solstitial *Points move backward.*

HENCE the *Solstitial* Points will always be receding from the *Stars* backwards, so that if the *Solstitial* Point be this Day near the *Star* A, after 72 Years it will be in B, one Degree removed towards the *West* of the *Star* A. And since the *Solstitial* Points move constantly backwards, the Æquinoctial Points which are always 90 Degrees distant from the *Solstices*, will also move constantly backwards; and so likewise must all the other Points of the Ecliptick necessarily move back, equally with the *Solstices*, because they keep constantly the same distances from them: Thus since between the *Solstice* and the intersection of the Æquator and the Ecliptick, there are 90 Degrees, or a Quadrant of a Circle, when the *Solstice* has moved one Degree *Westward*, the Æquinoctial intersection must likewise move one Degree *Westward*, otherwise they could not always keep the same distance from one another: Therefore the Æquinoctial Points, and all the other Points of the Ecliptick, do move continually backwards, or towards the *West*. And this Motion is said to be *in Antecedentia*, to the *Westward*, and contrary to the order of the Signs: As the other Motion whereby the *Earth* and all the Planets are carried round the *Sun* to the *Eastwards*, is said to be *in Consequentia*, in Consequence, or according to the Order of the Signs,

The Equinoctial Points move likewise backwards.

The Motions in Antecedentia.

The Motions in Consequentia.

that is,

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that is from ♈ to ♉ ♊, &c. And this backward Motion of the Æquinoctial Points, is called the *Preceſſion* of the Æquinoxes, by which they are carried conſtantly back unto the preceding Signs or *Stars*, and fall more and more behind the ſucceeding *Stars*.

The Motion of the Æquinoctial Points backwards makes the Stars *ſeem to move forwards, or to the* Eaſt.

SINCE the *fixed Stars* remain immoveable, and the common Interſection of the Æquator and the Ecliptick conſtantly falls backward, it muſt neceſſarily happen that the Diſtance of the *Stars* from the Æquinoctial Points be conſtantly changed, and the Interſections moving *Weſtward*, the *Stars* will ſeem to remove more and more *Eaſtward* in reſpect of the Æquinoctial Points: And therefore the Longitudes of the *Stars* which are computed from the firſt of Point ♈, or the Vernal interſection of the Æquator and Ecliptick, muſt conſtantly increaſe; and all the *Stars* will ſeem to have a Motion *Eaſtward*, not that they have really any ſuch Motion, but becauſe the Æquinoctial Point has a contrary Motion to the *Weſt*, ſo that the Diſtances of the *Stars* or their Longitude from the firſt Point of ♈ reckoned *Eaſtwards*, becomes conſtantly greater.

The Conſtellations have changed their places.

HENCE it is, that all the Conſtellations have changed their places, and have deſerted the Stations they kept when they were obſerved by the firſt *Aſtronomers.* Thus the Conſtellation of the *Ram*, which in *Hipparchus*'s time was near the Vernal interſection of the Æquator and Ecliptick, and gave its Name to that Portion of the Ecliptick, is now removed from that Interſection a whole Sign, or a twelfth Part towards the *Eaſt*, and is got into the Sign or Portion of the Ecliptick called ♉ or the *Bull*: Thus alſo the Conſtellation ♉ or the *Bull* does now reſide in *Gemini* or the *Twins*, and the *Stars* which are called *Twins* are at this Day advanced to ♋ or the *Crab*; the *Stars* in the *Crab* are got into the place which was formerly poſſeſſed by the *Lyon*, and the *Lyon* has driven the *Virgin* a whole Sign forward; and ſo every

Conſtellation

Constellation has since the first Observation changed place with the following. But here it is to be observed, that tho' the Constellations or Images have left their places, yet the twelve Portions of the Ecliptick, which are called *Dodecatimoria*, retain still the same Names which they had at first in the time of *Hipparchus*: But to distinguish them from the Constellations, the Portions of the Ecliptick are called *Anastrous* Signs, or Signs without *Stars*; and the Constellations are called the *Starry* Signs.

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SOME Antient *Astronomers* supposed the Intersections of the Æquator and Ecliptick to be immoveable, and because they found that the *Stars* changed their distances from these Intersections, they therefore imagined the Orb or Sphere in which the *fixed Stars* were placed, to have a slow Revolution about the *Poles* of the Ecliptick; so that all the *Stars* performed their Circulations in the Ecliptick or its Parallels, in the Space of 25920 Years; after which time the *Stars* would again return to their former places. This Period of time, which is five times greater than the Age of the World, they called the great Year; and imagined that when it was finished, every thing would begin again, and all things happen and come up in the same order they do now.

The great Year.

THE Physical and efficient cause of the Precession of the Equinoxies, was unknown to all the *Astronomers* before *Sir* ISAAC NEWTON; none of them being able to guess from whence it did proceed. But *Sir* ISAAC NEWTON having considered the Laws of Motion and Gravity, hath clearly demonstrated that it doth arise from the broad Spheriodical Figure of the *Earth*: And that this broad Spheriodical Figure arises from the Rotation of the *Earth* round its *Axis*.

ALTHO' the *Earth* in its Annual Motion does so go round the *Sun* that it always performs its Period in equal intervals of time; yet its Motion in its Orbit is observed not to be equable.

The Motion of the Earth *in its Orbit not equable.*

Lecture VIII.

ble and uniform, but in some places it moves quicker, in other places it slackens its pace; and therefore the Apparent Motion of the *Sun* in the Ecliptick cannot be regular and Uniform: And he is not observed to go thro' the same space of the Ecliptick every Day. In our Summer he is observed to go with a slower Motion, in our Winter he moves somewhat faster; and the difference of these Motions in Summer and Winter is such, that his place in the Ecliptick is sometimes two Degrees above what it would be, if he had constantly kept the same pace; and sometimes it is two Degrees less: On which account the *Sun* is observed to spend near eight Days more time in the *Northern* Signs of the Ecliptick, than in the *Southern* Signs; so that from the time of the *Sun*'s being in the *Vernal* Æquinoctie, 'till his coming into the *Autumnal*, there are $186\frac{1}{2}$ Days; in which time by his Apparent Motion he is seen to describe one half of the Ecliptick. But from the *Autumnal* Æquinoctie to the Vernal, there are only $178\frac{1}{2}$ Days, in which space of time he finishes his course thro' the other half of the Ecliptick, and visits all the *Southern* Constellations. We are also assured by the Observations of *Astronomers*, that the Apparent Diameter of the *Sun* in Winter, when the Motion of the *Sun* is quickest, is greater than the Apparent Diameter in the Summer, when he slackens his pace; and the Difference is so great, that when the *Sun* appears biggest, he is seen under an Angle of 32 Minutes 47 Seconds; but when he appears least, he subtends an Angle only of 31 Minutes and 40 Seconds, and therefore the *Sun* must be farther from us in Summer than in Winter.

Our Summer is eight Days longer than Winter.

The Apparent Diameter of the Sun greater in Winter than Summer

Some *Astronomers* too pertinaciously keeping to Circular Orbits, that they might give a Satisfactory account of these Appearances, supposed that the *Earth* did really move with an equable Motion in the Periphery of a Circle, and that if it were seen from the Center of that Circle,

Circle, it would be obſerved to deſcribe equal Angles round it; but they ſuppoſed the *Sun* to be removed from that Center at ſome diſtance. Let the Circle A B C D be the Orbit of the *Earth*, whoſe Center is E, and imagine the Center of the *Sun* not to be in E, but in S. Now when the *Earth* is in A, the *Sun* will be obſerved in the Point ♈, and when the *Earth* comes to B, the *Sun* will be obſerved in ♋: And again the *Earth* being arrived at C, the *Sun* will appear in ♎; ſo that while the *Earth* deſcribes the Arch A B C, which is more than a Semicircle, the *Sun* will appear to have gone thro' but one half of the Ecliptick; and the *Sun* will ſeem to have performed his Journey thro' the other half, while the *Earth* is deſcribing the other Portion of her Orbit A D C. Now ſince the Arch A B C is greater than the Arch A D C, it is eaſy to ſee that the *Sun* muſt take more time to deſcribe, by its apparent Motion, that half of the Ecliptick ♈, ♋, ♎, than the other ♎, ♑, ♈. Moreover when the *Earth* is in B, it is further diſtant from the *Sun* than when it is in D: And if its Motion were in itſelf perfectly equable, yet when it is ſeen from the *Sun*, which is not the Center of equable Motion, it would from thence appear to be unequal: In B it would appear to be ſloweſt of all, and in D to be the quickeſt of all. But the Apparent Motion of the *Sun* in the Ecliptick is conſtantly equal to the Motion of the *Earth* ſeen from the *Sun*; and therefore by this Suppoſition we can give an eaſy account why in our Summer the *Sun* appears to have a ſlow Motion, and in the Winter a quicker; ſo that the unequal Motion of the *Sun* or *Earth* is not ſo in reality, but only Opticall and Apparent; ariſing only from this, that the *Sun* is not exactly in the Center of the *Earth*'s Orbit in E, but at ſome diſtance from it at S: So they affirmed that a Spectator in E would

Lecture VIII.

Plate IV. Fig. 3. *The Motion of the* Earth *in an Excentrick Circle.*

Lecture VIII.

always Observe that the *Earth* had a most exact uniform Motion round that Center in its Orbit.

THIS *Hypothesis* appears at first sight to be simple enough, and to answer well the Appearances we have related; and all the *Astronomers* before *Kepler* embraced it as a true *Hypothesis*. For they held it for an undoubted truth, that all the Motions of the Heavens were axactly Circular, and in themselves equable: But after the Great *Kepler* had more accurately surveyed these Motions, and relying upon the Observations of the most Industrious *Tycho Brahe*, he then found that the Circular *Hypothesis* would by no means answer to the true Motions of the *Planets*: And by a most certain and infallible Method of reasoning, he has shown that the Motions of the *Planets* are neither equable in themselves, nor are their Orbits exact Circles. For by the Observations of *Tycho*, he has proved beyond all dispute, that the Figure of a Planetary Orbit is an *Ellipse*, which is deficient from a Circle, or of the form of an Oval; and that the *Planets* Motion in this Ellipse is really unequal, sometimes quicker, and sometimes slower; and that according to its distance from the *Sun* the *Planet* slackens or quickens its Motion.

The true Motions of the Planets *are neither in Circles nor equable.*

The Elliptick Orbits of the Planets.

NOW the *Ellipsis* is a curved Line Figure, which the *Geometers* commonly shew by cutting a Cone or a Cylinder obliquely: But its nature will be more clearly apprehended by beginners, from the following Description. Imagine two small round Sticks to be fastned in any Plane or Paper, one in the Point H, the other in the Point G; and suppose a Thread doubled with the two ends tyed together, whose length must be greater than the distance of the Points G and H, which Thread put over the two round Sticks: And let there be a Pen put in the doubling of the Thread, which may keep it always stretched with the same force. This Pen going in this manner round will describe by it

Plate IV. Fig. 4. *The Description of an Ellipse.*

its Motion a curve Line, which is the *Ellipse* we now speak of. And if without changing the length of the Thread, we should bring the round Sticks a little closer together, we shall then have another Ellipse of a different kind from the former, and which will come nearer to a Circle: And by bringing them still nearer, we shall always change the Form of our Ellipse, and bring it nearer to a Circle, 'till the Sticks come to be joined together in one; and then the Pen in the doubling of the Thread will describe an exact Circle. Either of the Points G or H is called the *Focus* or Navil of the Ellipsis, and if we bisect H G in C, the Point C is called its Center; the Line D K passing thro' each *Focus*, and at each end meeting with the Ellipse, is called its *Axis*: Hence it is evident, that if from any Point of the Ellipsis, there be drawn to the two *Focus*'s, as for Example from B, two Lines B H and B G, these two Lines joined together will always be equal to the *Axis* of the Ellipsis, and likewise equal to the length of the Thread, bating the Distance of the two *Focus*'s.

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The Focus *or* Umbilicus.

NOW tho' this be the Form of the Orbit which the *Planets* describe, yet the Place of the *Sun* is not the Center of it, but he takes his Residence in one of the *Focus*'s: And the *Axis* of the Ellipse A P, is called the Line of the *Apsides*; the Point A is termed the *higher Apsis*, and the *Aphelion*; the Point P is called the *lower Apsis*, and the *Perihelion*: And S C the Distance between the *Sun* in the *Focus* and the Center, is called the *Excentricity*. If from the Center C, there be erected upon the *Axis* the Perpendicular C E, meeting with the Orbit in E, and there be drawn from the *Focus* the Line S E; this Line is called the *Mean Distance* of the *Planet* from the *Sun*, which is equal to half the *Axis*; it exceeding the shortest Distance by as much as the longest Distance exceeds it.

The Axis.

Plate IV. Fig. 5.

The higher Apsis *or* Aphelion.

The lower Apsis *or* Perihelion.

The Excentricity.

The Mean Distance.

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IN the Planetary Orbits, the Forms of the Ellipses do not differ much from Circles; and in the Orbit of the *Earth*, the Excentricity SC is only 17 of such parts as SF the Mean Distance consists of a 1000, which Excentricity is but half of that which the *Astronomers* that supposed Circular Orbits, attributed to the Distance of the *Sun* from the Center.

The Rule by which the Planets Motions are regulated, is the equable description of Elliptick Areas.

THE Motion of a *Planet* in the Periphery of an Ellipse, is not at all equable; yet it is regulated by a certain immutable Law, from which it never deviates; which is, that a Line or Ray drawn from the Center of the *Sun* to the Center of the *Planet*, which is carried about with an Angular Motion, does so move, that it describes or sweeps an Elliptick *Area*, always proportional to the Time. Thus, let the *Planet* be in A, from whence in a certain Time let it go to B; the Space or Area the Ray SA describes is the Triline ASB: When afterwards the *Planet* comes to P, and from the Center of the *Sun* S, there be drawn the Line SD, so that the Elliptick Space or Area PSD, may be equal to the Area ASB; then in that Case, the *Planet* will move thro' the Arch PD, in the same compass of time that it did thro' the Arch AB, which Arches must be unequal, and nearly in a reciprocal proportion to their Distances from the *Sun*; for because of the equal Area's, the Arch PD must be so much in proportion greater than the Arch AB, as SA is greater than SP. This Law is sufficiently demonstrated by the most Sagacious *Kepler*, in his Book which he entituled, *Commentaries on the Motion of the Planet* Mars. And unto this his Invention all the *Astronomers* do now give their Assent; for there is no other Rule to be found, which so well satisfies all the Appearances of the *Planets* Motions.

The Mean Anomaly.

AN Arch of a Circle, or an Angle, or the Elliptick Area ASG, taken proportional to the Time in which the *Planet* descends from A to G, is called the *Mean Anomaly* of the *Planet*. But

the Angle ASG when the *Planet* comes from A to G, is called its *True Anomaly.* But when the Motion of the *Planet* is reckoned from the vernal Interſection of the Æquator and the Ecliptick, or from the beginning of ♈, it is called its *Motion in Longitude*; which is either a Mean Motion, ſuch as the *Planet* would have, did it move uniformly in a Circle round the *Sun*, or elſe the true Motion wherewith the *Planet* deſcribes its Orbit, and is reckoned by the Arch of the Ecliptick it is ſeen to deſcribe; which true Motion is ſometimes accelerated, and ſometimes retarded, according to the Diſtance of the *Planet* from the *Sun*, in the various Points of its Orbit.

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The True Anomaly.

The Motion in Longitude.

BY this means, for any given Time after that the *Planet* has left its *Aphelion*, we find out its Place in its Orbit, *viz.* Let the Area of the Ellipſe be ſo divided by the Line SG, that the whole Elliptick Area may have the ſame proportion to the Area ASG, as the whole Periodical time wherein the *Planet* deſcribes its Orbit, is to the Time given; and then G will be the Place of the *Planet* in its Orbit. The *Geometers* have given ſeveral Methods for dividing in this manner the Area of an Ellipſe, ſome of which we will ſhew in its proper Place.

The determination of a Planet's *Place in its Orbit.*

SINCE in our Summer we are further from the *Sun*, and when Winter comes on we begin to approach him; ſome may wonder why the *Earth* grows warmer while it is ſtill further removing from the *Sun*; and again in the Winter why it ſhould be colder notwithſtanding its nearer acceſs to him. But we muſt obſerve that the degrees of Heat and Cold do not altogether depend upon the Diſtances from the *Sun*, but there are other powerful and concurring Cauſes, which have certain effects in this matter: For firſt of all, the direct force of the *Sun*'s Rays is much ſtronger than when they are received obliquely: Now in the Winter the Rays fall upon the *Earth* very obliquely, and their Power is not only diminiſhed on the account of their obliqueneſs, but

Why the Sun's *Heat is greater as he is further from us.*

Lecture VIII. alſo becauſe the Light is not ſo denſe, there being much fewer rays which can come to a certain Portion of the Surface to Heat it. Moreover the *Sun* being low in the *Horizon* all the Winter, the Beams paſs thro' a much greater quantity of Air, or are deeper immerſed in our Atmoſphere in the Winter, than they are in Summer, when the *Sun* approaches nearer to our Vertex, and the Force of the Rays is broke by the Reflections on ſo many Particles of Air: And the difference is ſo very great, that when the *Sun* is in the *Horizon*, we can look upon him without hurting our Eyes; but when he Riſes higher, there is no enduring his ſight without blinding us.

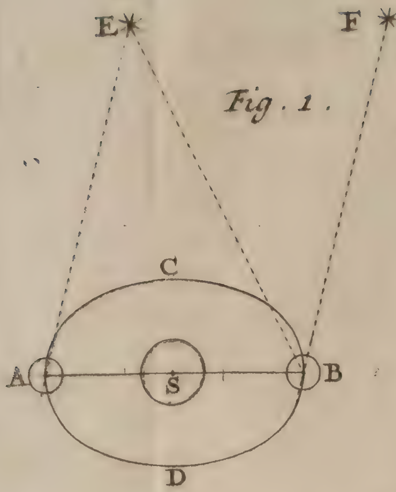
The Days longer than the Nights, increaſe the Heat.

BUT there is another very powerful Cauſe which produces the variety of Seaſons, which is, that the longer any hard and ſolid Body is expoſed to the Fire, the Hotter it grows. Now in the Summer for ſixteen Hours we are continually in the *Sun*'s heat, and we have only eight Hours in the Night to cool: The contrary of which happens in the Winter, and therefore it can be no Wonder that there ſhould be ſo great a difference of Heat and Cold, in theſe two Seaſons.

SINCE the Power of the *Sun* is greateſt when his Rays fall upon us moſt directly, and when the Days are longeſt; it would ſeem that the greateſt Heat ought to be when the *Sun* enters the Tropick of ♋, for then the *Sun* comes neareſt to our Vertex, and lieth longeſt upon us. But Experience ſhews us, that we have the greateſt Heat after that the *Sun* has left the Tropick; and the Seaſon becomes warmeſt about the end of *July*, in the *Dog-Days*, when the *Sun* has paſſed the Tropick, and is removed from it above a whole Sign.

THAT we may give the true Cauſe of this effect, it is to be obſerved, that the Action of the *Sun* by which all Bodies are heated, is not tranſient, as its Illumination is, but permanent: So that a Body which has been once heated by the *Sun*, retains its Heat for ſometime after the *Sun* has

gone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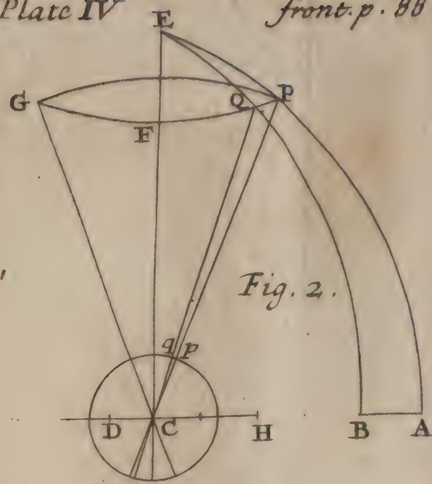
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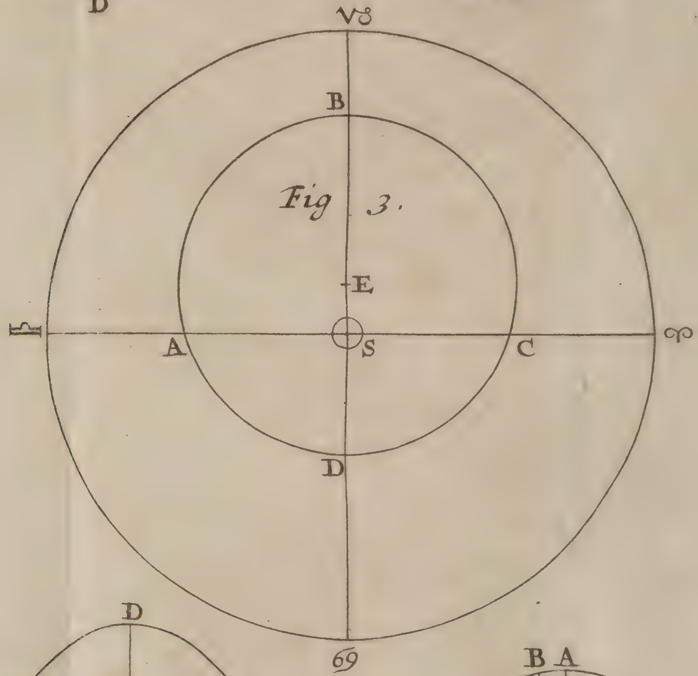
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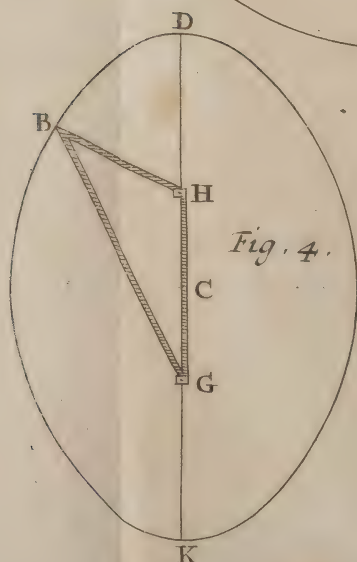
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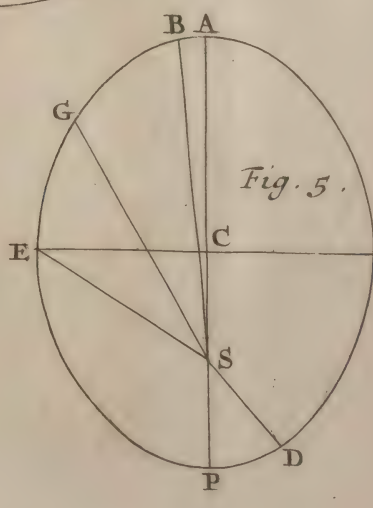
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gone off it: So that the heating Particles which flow from the *Sun*, and are abſorbed by the heated Body, do for a certain time remain within it, and do therein raiſe a warmth or Heat. But afterwards when theſe Particles fly off, or looſe their Force, the Body begins to cool: And therefore, if the heating Particles which are conſtantly received be more than they which flie away or looſe their Force, the Heat of the Body muſt continually encreaſe. And this is our preſent Caſe: After the *Sun* has entred the *Tropick*, the number of Particles which Heat our Atmoſphere and *Earth*, does conſtantly encreaſe, there entering more in the Day time than what we looſe in the Night time, and therefore our Heat muſt grow greater. Let us ſuppoſe for Examples ſake, that there are a Hundred heating Particles received in the Day-time in *Sun* ſhine, and the Night being much ſhorter, there ſhould fly off only fifty of them, other fifty ſtill remaining there to excite Heat: The next Day the *Sun* acting with almoſt the ſame Force, will impart another Hundred Particles, of which no more than one half will fly away in the Night; ſo that on the beginning of the third Day, the number of Particles exciting Heat will be encreaſed by one Hundred: And thus while there are more Particles that excite Heat received in the Day time, than what fly away in the Night, the Heat will conſtantly grow ſtronger. But then as the Days decreaſe, and the Action of the *Sun* becomes weaker, there will at laſt be more Particles that fly away in the Night time, than what we receive in the Day time; by which means the Heat of a Body will grow every Day leſs, and the *Earth* and Air will by degrees Cool.

Why the Heat is not greateſt when the Sun *is in the Summer* Tropick.

LEC-

LECTURE IX.

Of the Moon, *its* Phases *and Motion.*

The Moon *is an Attendant on the* Earth.

OF all the Bodies in the Heavens, if you except the *Sun*, the *Moon* appears to us to be the most Splendid and shining Globe, and does more particularly belong to our *Earth*, of which she is an inseparable Companion. And she does constantly abide so much in our Neighbourhood, that if she were looked at from the *Sun*, she could never be seen to depart from us by an Arch greater than ten Minutes: She therefore is tyed to the *Earth*, and waits upon her as an Attendant, going along with the *Earth* round the *Sun* in the space of a Year; but in the mean time she has a proper Orbit of her own which she describes round the *Earth*, in the time of a Month.

It has various shapes and Phases.

THE Primary *Planets* have the *Sun*, which they regard as a Center, for the Regulator of their Motions; and sometimes they approach us nearly, at other times they move away to a great Distance from us. But the *Moon* like an Earthly Body is kept in our Neighbourhood by a Natural Propension or Gravity towards us; by the means of which it is constantly turned out of a rectilinear Course, and is obliged to perform its Revolution round about us, in the space of 27 Days and seven Hours. The *Moon* puts on several Phases or Appearances, and is always changing its Figure; and with the multitude of her Forms she has frequently puzled the Minds and Understandings of those *Philosophers*, who have most Contem-

plated

plated her: Sometimes ſhe encreaſes and grows bigger, then ſhe again wanes, and diminiſhes as it were in old Age; ſometimes ſhe is bended into *Horns*, and then again ſhe appears like a half Circle; at other times ſhe looks Gibbous or Hump-backed, and immediately ſhe aſſumes a full globular Face; and afterwards by degrees ſhe diſappears and loſes all her Luſtre; ſometimes ſhe inlightens us the whole Night, at other times ſhe does not appear 'till late at Night: And even in a Total Eclipſe ſhe is frequently viſible, tho' with a very languid and pale Countenance; ſometimes ſhe keeps in the *Southern* Region of the Heavens; at other times, ſhe riſes high, and viſits the *Northern* Hemiſphere. All theſe Things were firſt found out by *Endymion* among the *Greeks*, who was the firſt among them who watched her Motions, and upon that Account was ſuppoſed to have fallen in Love with her.

Lecture IX

The Moon *is a Spherical Opake Body.*

THE *Moon*, like the *Earth*, is a Dark, Opake, and Spherical Body; and only ſhines with the borrowed Light of the *Sun*: For it is the *Sun* who is the great Luminary in our Syſtem, and who always Illuſtrates that half of the *Moon*'s Body, which is turned towards him; whilſt the other half which is oppoſite, is involved in Darkneſs: But the Face of the *Moon*, that can be ſeen by the Inhabitants of the *Earth*, is that which is turned toward the *Earth*: And therefore according to the various Poſition of the *Moon*, in reſpect of the *Sun* and *Earth*, we do obſerve different Illuminations and degrees of Illuſtration; at one time a larger, at another a leſſer Portion of the illuminated Surface is to be ſeen; ſometimes there is no Part of it viſible, and ſometimes we obſerve the whole, and ſee the *Moon* with her Full Face. But for the better underſtanding of this matter, we will explain it by a Figure. Let S repreſent the *Sun*, T the *Earth*, R T S a Portion of the *Earth*'s Orbit, which it deſcribes in its Annual Courſe round

Plate V. Fig. 1, 2.

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round the *Sun*. Let ABCDEFG be the Orbit of the *Moon*, in which ſhe turns round the *Earth* in the ſpace of a Month, from the *Weſt* towards the *Eaſt*.

The true Motion of the Moon *from* Weſt *to* Eaſt.

THIS Motion of the *Moon* is evident to our Senſes; for if the *Moon* be obſerved to arrive at the Meridian any Night with a *fixed Star*, the next Night ſhe will be 52 Minutes later in coming to the Meridian or in *Southing*, than the *Star*, ſhe having receded from the *Star* about 13 Degrees towards the *Eaſt*. Join the Centers of the *Sun* and *Moon* with the right Line SL, and thro' the Center of the *Moon* imagine a Plane MLN to paſs, to which the Line SL is Perpendicular: The Section of that Plane with the Surface of the *Moon*, will produce the Circle which bounds Light and Darkneſs in her; and ſeparates the inlightned Face from the Dark and obſcure ſide. In the ſame manner let the Centers of the *Earth* and *Moon* be joined by the right Line TL, which is Perpendicular to a Plane PLO paſſing thro' the Center of the *Moon*; that Plane will make on the Surface of the *Moon*, the Circle which diſtinguiſheth the viſible Hemiſphere, or that which is towards us, from the inviſible which is turned from us; which Circle may therefore be termed the *Circle of Viſion*.

The Circle in the Moon *bounding Light and Darkneſs.*

The Circle of Viſion.

The Phaſes of the Moon *explained.*

HENCE it is manifeſt that, whenever the *Moon* is in the Poſition A, in the Point of its Orbit oppoſite to the *Sun*, that then the Circle bounding Light and Darkneſs, and the Circle of Viſion do coincide; and that all the illuminated Face of the *Moon* will be turned towards the *Earth*, and be viſible by its Inhabitants: And then the *Moon* is ſaid to be Full, and ſhe Shines all Night long; and in reſpect to the *Sun* ſhe is ſaid to be in *Oppoſition*: For the *Sun* and *Moon* are ſeen in oppoſite Parts of the Heavens, the one riſing when the other Setts. When the *Moon* comes to B, the whole illuminated Disk MPN is not turned towards the *Earth*, there

being

being a Part of it M P not to be ſeen by us; and then the *Viſible Illumination* will be deficient from a Circle, and the *Moon* will have a gibbous or Humped Form, ſuch as is marked in B. *The Gibbous Figure.* The *Moon* arriving at C, where the Angle C T S is nearly right, there only one half of the illuminated Disk is turned towards the *Earth*, and to be ſeen from thence; and then we obſerve a *Half-Moon* as in C, and ſhe is ſaid then to be *Biſected* or *Dichotomized*, that is cut in halfs. *Half* Moon, *or the* Moon *Dichotomized.* In this Situation the *Sun* and *Moon* are a fourth part of a Circle removed from each other, and the *Moon* is ſaid to be in a *Quadrate Aſpect*, or to be in her *Quadrature*. *The* Quadrature. The *Moon* going forward to D, the illuminated Face MPN, has but a ſmall Portion of its ſelf turned towards the *Earth*, and the ſide of the Moon turned towards the *Earth* is for the greateſt part in Darkneſs: And therefore of the Spherical figure of the *Moon* which appears to us to be Plane, that ſmall Part which ſhines upon us will ſeem to be bended into narrow Points or Angles, and will look like what we call Horns; for there the Circle bounding Light and Darkneſs with the Circle of Viſion, doth form two ſmall Angles at their Interſections, and the *Phaſis* ſeen from the *Earth* will appear as in D. The *Moon* at laſt coming to E, will ſhew no part of its illuminated Face to the *Earth*, but all the dark ſide of the *Moon* will be turned towards it; and then the *Moon* diſappears, and ſhe is ſaid to be in *Conjunction* with the *Sun*, the *Sun* and ſhe being in the ſame Point of the Ecliptick. *New* Moon, *or the* Conjunction. This Poſition we call *New Moon*. When the *Moon* advances further to F, ſhe again aſſumes a Horned or Crooked Figure; and as before the New *Moon* the Horns were turned *Weſtward*, ſo now after the time of New *Moon*, they change their Poſitions and look *Eaſtward*. When the *Moon* has proceeded to G, and is again in a *Quadrate Aſpect* with the *Sun*, ſhe will appear Biſected, and like a *Half-Moon*. In H ſhe will be bigger, but will ſtill be deficient from a whole Circle, and be ſeen Gibbous: But

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But in A she will again appear Circular, and in her full Splendor.

The Elongation *of the* Moon *from the* Sun.

THE Arch EL, or the Angle STL, contained under Lines drawn from the Centers of the *Sun* and *Moon* to the Center of the *Earth*, is called the *Elongation* of the *Moon* from the *Sun*. And the Arch MO, which is that Portion of the illuminated Circle MON which is turned towards the *Earth*, and which is the Measure of the Angle that the Circle bounding Light and Darkness and the Circle of Vision make with one another, is every where nearly similar to the Arch of Elongation EL, or, which is the same thing, the Angle STL is nearly equal to the Angle MLO, which I thus demonstrate. Produce SL at pleasure unto X, and the Angles TLP and MLS will be equal, they being both Right Angles: But the Angles OLS and PLX are also equal, because they are Vertical to each other; therefore taking away those equal Angles, the Angle MLO will remain equal to the Angle TLX; but the Angle TLX is the external Angle of the Triangle STL, and is therefore equal to both the inward and opposite Angles STL and TSL, by the 32d Proposition of Book I of *Euclid*. But the Angle TSL is exceeding small and next to nothing; for when biggest, in the Quadratures it does scarce exceed ten Minutes of a Degree; the Distance of the *Moon* from the *Earth* in comparison of that of the *Sun* being so small, that the Angle which it subtends at the *Sun* vanishes. And therefore the Angle STL by it self, is nearly equal to the Angle MLO; whence the Arch MO will be similar or like to the Arch EL.

THE Semicircle OMP, since its Plane passes thro' the Eye, will be projected into a Right Line, or appear like a Right Line on the Disk of the *Moon*; but the Circle bounding Light and Darkness in the *Moon*, since it is seen Obliquely from the *Earth*, will be projected into an Ellipse, in which Form it will appear. Hence having

having the Elongation of the *Moon* from the *Sun*, it will be an eaſie matter to ſhew its *Phaſis*, or how it appears at that time. Let the Circle COBP repreſent the Diſk of the *Moon* which is turned towards the *Earth*; and let OP be the Line in which the Semicircle OMP is projected, which ſuppoſe to be cut by the Diameter BC at Right Angles; and making LP the Radius, take LF equal to the Coſine of the Elongation of the *Moon* from the *Sun*: And then upon BC, as the great *Axis*, and LF the leſſer *Axis*, deſcribe the Semi-Ellipſe BFC. This Ellipſe will cut off from the Diſk of the *Moon* the Portion BFCP of the illuminated Face, which is viſible to us from the *Earth*.

Lecture IX.

A Delineation of the Phaſis of the Moon, *for any Elongation.*

Plate V. Fig. 3, 4, 5.

BY making LP the Radius, LF becomes the Coſine of the Elongation of the *Moon* from the *Sun*; PF in that caſe muſt be the Verſed Sine of the ſaid Elongation; and BFC (the Line which divides the illuminated and dark Parts of the Diſk) will be an Ellipſe, whoſe greater *Axis* is the Diameter of the Diſk BC, and half the leſſer *Axis* is the Semidiameter of the ſame Diſk, diminiſhed by the Verſed Sine of the Elongation. Suppoſe now that OBPC were the Diſk of the *Moon* turned towards the *Earth*, and BFC the Semi-Ellipſe dividing Light and Shadow: Draw any Line GHN parallel to the leſſer *Axis*, and which meets with the greater *Axis* in M, by the Nature of the Circle and the Ellipſe, LP will be to LF as GM is to MH; and by Diviſion of Ratio, LP is to PF as GM is to HG; and doubling of the Antecedents, PO will be to PF as GN is to GH. The ſame thing may be ſhewen of any other Line which is Parallel to the leſſer *Axis*, and therefore by the 12th Prop. Book V. Of *Euclid*, as PO is to PF ſo will all the Lines GN be to all the Lines GH. But all the Lines GN compoſe or make up the whole *Lunar* Diſk, it conſiſting of an infinite number of Parallelograms, whoſe Heights are the Lines GN, and

The Quantity of Illuſtration.

Lecture IX.

and whose Bases are indefinitely little: So likewise all the Lines GH make up that part of the Disk which is illuminated.

AND therefore as PO is to PF, that is as the Diameter of a Circle, is to the versed Sine of the *Moon*'s Elongation from the *Sun*; so is the whole Disk of the *Moon*, to that part of it which is illuminated by the *Sun*. And hence the Illustration of the *Moon* at any time, is to its greatest Illustration, which is at *Full Moon*, as the versed Sine of the Elongation, is to the Diameter of a Circle.

The Earth *Illuminates the* Moon *by a Reflex Light.*

AS the *Moon* by reflected Light from the *Sun* illuminates the *Earth*, so the *Earth* does more than repay her kindness, in enlightning the Surface of the *Moon*, by the *Sun*'s reflex Light, which she diffuses more abundantly upon the *Moon*, than the *Moon* does upon us: For the Surface of the *Earth* is above fifteen times greater than that of the *Moon*; and therefore if both Bodies have the same power in Reflecting in proportion to their bigness, the *Earth* would send back fifteen times more Light to the *Moon*, than it receives from it. For the *Earth* appears fifteen times bigger to the Inhabitants of the *Moon*, than the *Moon* does to us. In new *Moons* the Illustrated side of the *Earth*, is fully turned towards the *Moon*, and will therefore at that time illuminate the dark side of the *Moon*; and then the *Lunarians* will have a *Full Earth*, as we in a similar Position have a *Full Moon*. And from thence arises that dim Light which is observed in the Old and New *Moons*, whereby besides the bright and shining Horns, we can perceive the rest of her Body behind them, tho' but dark and obscure. Now when the *Moon* comes to be in *Opposition* to the *Sun*, the *Earth* seen from the *Moon* will appear in *Conjunction* with him, and its dark side will be turned towards the *Moon*, in which Position the *Earth* will disappear; after the same manner as the *Moon* does disappear to us in the time of *New Moon*, or her in *Conjunction* with the

the *Sun*. After this the *Earth* will appear to the Inhabitants of the *Moon* in a Horned Form. In a Word the *Earth* will ſhew all the ſame Appearances to the Inhabitants of the *Moon* as the *Moon* does to us.

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ALTHO' the *Moon* circulating round the *Earth* deſcribes its Orbit in the Space of 27 Days and ſeven Hours, which ſpace of Time is called a Periodical Month; yet the time the *Moon* takes to go from one Conjunction to the next, which is a Synodical Month or a *Lunation*, is greater than the Periodical. For while the *Moon* in its proper Orbit finiſhes its Courſe, the *Earth*, with this her Companion and its Orbit, are going on their way round the *Sun*, and are advanced almoſt a whole Sign towards the *Eaſt*; ſo that the Point of the Orbit which in the former Poſition was placed in a Right Line joining the Centers of the *Earth* and *Sun*, is now more *Weſterly* than the *Sun*: And therefore when the *Moon* has again arrived to that Point, it will not yet be ſeen in Conjunction with the *Sun*.

The Periodical Month, and the Synodical.

FOR let AB repreſent a Portion of the Orbit of the *Earth*, and when the *Earth* is in T, ſuppoſe the *Moon* in L, in Conjunction with the *Sun* in S: while the *Moon* leaves the Point L, and proceeds in deſcribing its Orbit LACD; the *Earth* in the mean time by its Motion round the *Sun* is carried in the Arch T*t*, and when it is come to *t*, the Orbit of the *Moon* is in the Poſition *l a c d*, and the Point of the Orbit L will now be in the Line *t l*, which is Parallel to the former Line TL: Hence it is plain, that when the *Moon* has come to *l*, and deſcribed its whole Orbit, that it is not then arrived at a Conjunction with the *Sun*, but it muſt ſtill go further and move thro' the Arch *l*M, before it can get between the *Earth* and *Sun*: And ſince the *Moon* finiſhes her Courſe in the ſpace of 27 Days, in that time the *Earth* will have compleated an Arch of 27 Degrees in the Ecliptick; now the Arch *l*M and T*t* are alike or ſimilar, becauſe the Lines

Plate V, Fig. 6.

Lecture IX.

L T, and *l t*, being Parallel, the Angles *l t* M and L S M are equal. But indeed it is required that the *Moon* should describe a greater Arch than *l* M, before it gets between us and the *Sun*, because the *Earth* is still moving on in the mean time: And therefore the whole *Lunation*, or time from *New Moon* to *New Moon*, is not finished but in the space of 29 Days and a half; And the *Moon* does every Day recede from the *Sun*, about 12 Degrees and some odd Minutes, which is called the diurnal Motion of the *Moon* from the *Sun*.

The diurnal Motion of the Moon *from the* Sun.

IF the Plane of the *Moon*'s Orbit coincided with the Plane of the Ecliptick, that is, if the *Earth* and *Moon* moved both in the same Plane, the way of the *Moon* in the Heavens seen from the *Earth*, would be exactly the same with the Circle the *Sun* is seen to describe; only the *Sun* would be observed to describe that Circle in the space of a Year, which the *Moon* does in a Month. Now in reality the Plane in which lies the *Moon*'s Orbit, is not coincident with the Plane of the Ecliptick: but these two Planes cut one another in a Right Line, which passes thro' the Center of the *Earth*; and they are inclined to one another in an Angle of about five Degrees.

Plate V. Fig. 7.

The Moon *does not move in the Ecliptick.*

LET A B be a Portion of the *Earth*'s Orbit, T the *Earth*, and let the Circle C E D F represent the Orbit of the *Moon*, in which is the Center of the *Earth*: with the same Center T, in the Plane of the Ecliptick, let there be described another Circle C G D H, whose Semidiameter may be equal to the Semidiameter of the *Moon*'s Orbit; these two Circles being in different Planes, and having the same Center T, will intersect each other in a Line D C, which passes thro' the Center of the *Earth*; and C E D, one half of the Orbit of the *Moon*, will rise above the Plane of the Circle C G H, towards the *North*. The other half of the Orbit D F C will be depressed below it, towards the *South*. The Right Line D C wherein the

the two Circles cut one another, is called the Line of the *Nodes*; and the Points of the Angles C and D are called the *Nodes*. And the *Node* C, where the *Moon* ascends *Northward* above the Plane of the Ecliptick, is called the *Ascending Node*, and the *Head of the Dragon*, and is thus Marked ☊. The other D, from whence the *Moon* descends to the *South*, is named the *Descending Node*, and the *Tail of the Dragon*, which by the *Astronomers* is marked in this manner ☋. If the Line of the *Nodes* were immoveable, that is if it had no other Motion than that whereby it is carried round the *Sun*, it would always look to the same Point of the Ecliptick; that is, it would always keep Parallel to it self, as we shewed the *Axis* of the *Earth* ought to do: But we find by Observation that this Line of the *Nodes* does constantly change its Place, and shifts its Situation from *East* to *West*, contrary to the Order of the Signs; and by a Retrograde Motion finishes its Circulation in the compass of almost 19 Years: After which time either of the *Nodes* having receded from any Point of the Ecliptick, returns to the same again. And when the *Moon* is in the *Node*, she is also seen in the Ecliptick.

Lecture IX.

The Line of Nodes.

The Ascending Node, *or the* Dragon's *Head.*

The Descending Node, *or the* Dragon's *Tail.*

The Retrograde *Motion of the* Nodes.

HENCE it is evident, that the *Moon* can never be observed precisely in the Ecliptick, but twice in every Period, that is when she enters the *Nodes*; when she is in any other place of her Orbit, she deviates from it, and is sometimes nearer, sometimes further removed from the Ecliptick, according as she happens to be nearer, or further off from the *Nodes*: But she is at her greatest Distance from the *Nodes*, when she is in the Points of her Orbit E or F, which are the middle Points between the *Nodes*; and these Points are called the *Limits*. The Distance of the *Moon* from the Ecliptick is called her *Latitude*, which is measured by an Arch of a Circle drawn thro' the *Moon*, Perpendicular to the Ecliptick; the Arch of this Circle intercepted

The Limits.

The Moon's Latitude.

Lecture X.

between the *Moon* and the Ecliptick, measures the *Moon*'s *Latitude*, or her Distance from the Ecliptick: And therefore such Circles perpendicular to the Ecliptick, are called Circles of *Latitude*; the *Latitude* of the *Moon* when it is at the biggest, as in E or F, does never exceed five Degrees and about eighteen Minutes, which *Latitude* is the Measure of the Angles at the *Nodes*.

LECTURE X.

Of the Inequalities in the Lunar *Motions. The Face of the* Moon, *her Mountains and Vallies.*

The Orbit of the Moon *an Ellipse.*

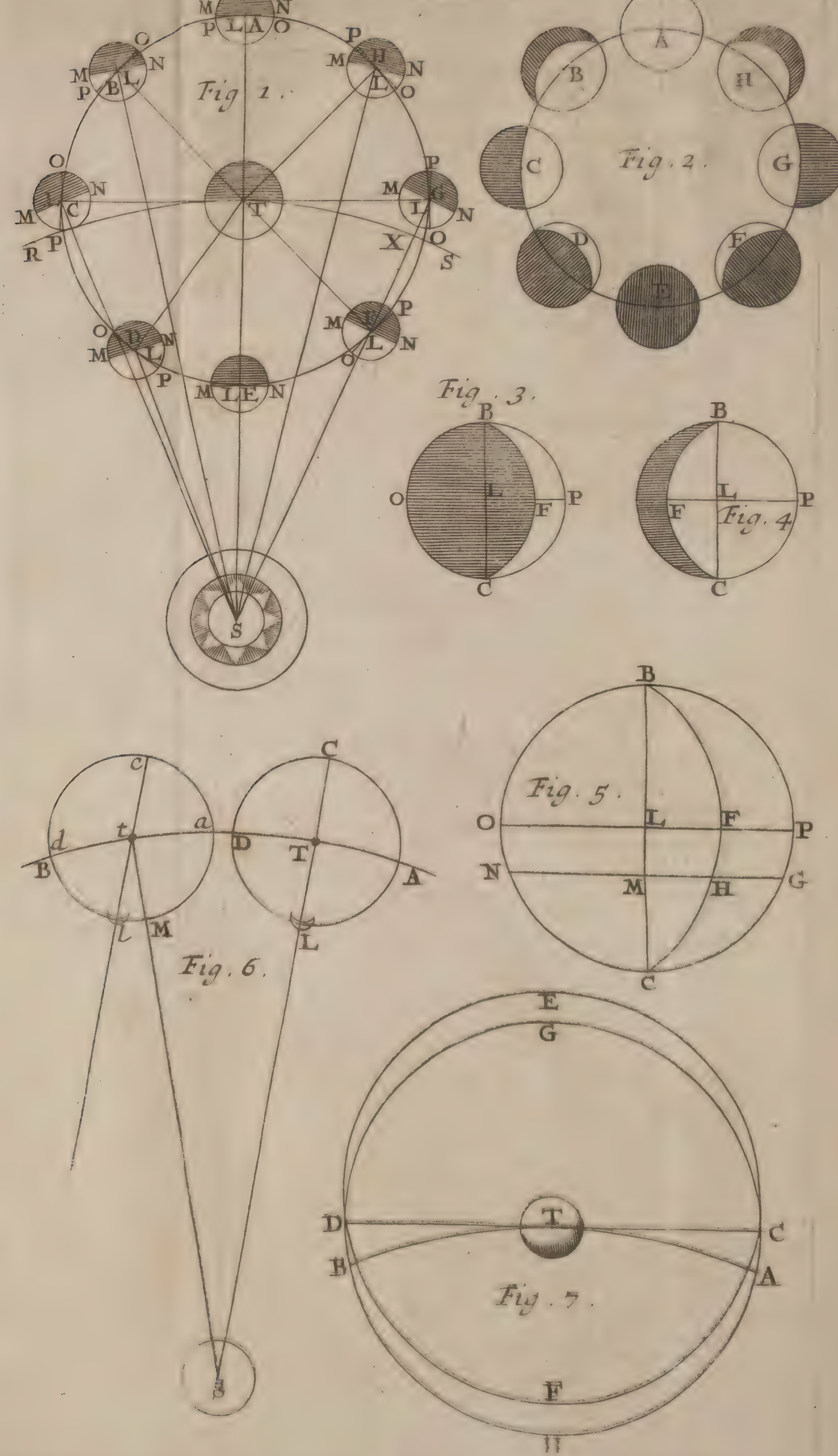
OBSERVATIONS have discovered to us that the Distance of the *Moon* from the *Earth* does constantly change; sometimes the *Moon* comes nearer to us, sometimes goes further from us; the reason of which is because the *Moon* does not move in a circular Orbit, which has the *Earth* for its Center: But the real Orbit of the *Moon* is of an Elliptick Form, such as is represented in the Figure ABPD, one of whose *Focus*'s is always the Center of the *Earth*; AP is the greater *Axis* of the Ellipse and the Line of the *Apsides*; TC is the Eccentricity, the Point A which is the highest *Apsis*, is called the *Apogeon* of the *Moon*; the lowest *Apsis* which is the Point P, is called the *Perigeon*, in which the *Moon* comes nearest the *Earth*. And if the Orbit of the *Moon* had no other Motion besides that wherewith it is carried round the *Sun*, it would always

Plate VI. Fig. 1.

The Moon's Apogoen *and* Perigeon.

Plate V

front. p. 100



ways retain a Poſition parallel to it ſelf, and would always point the ſame way, and be obſerved in the ſame Point of the Ecliptick; and whenever the *Moon* came to that Point, it would conſtantly be at the ſame Diſtance from us: But this Line of the *Apſides* is likewiſe obſerved to be moveable, and to have an Angular Motion round the *Earth* from the *Weſt* towards the *Eaſt*, according to the Order of Signs, ſo that it does not return to the ſame Situation, 'till after the ſpace of almoſt nine Years.

The Inequalities of the Motions of the Moon.

THE Motions of the *Moon*, and that of her Orbit, do not obſerve the ſame Inequalities. For firſt, when the *Earth* is in her *Aphelion*, at the greateſt Diſtance from the *Sun*, the *Moon* being ſo likewiſe, the *Moon* does ſomewhat quicken her pace, and performs her Circulation in leſs time. On the contrary, when the *Earth* approaches nigheſt to the *Sun* in the *Perihelion*, the *Moon* is likewiſe nearer, and then ſhe ſlackens her Motion: Upon which Account it is that the *Moon* revolves about the *Earth* in ſhorter time when the *Earth* is in her *Aphelion*, than when ſhe is in her *Perihelion*; ſo that the Periodical Months are not all equal.

Syzygia.

Secondly, When the *Moon* is in the *Syzygia*, that is, in the Line which joins the Centers of the *Earth* and *Sun* (which may be either in her Oppoſition or Conjunction) all other things being alike, ſhe has a ſwifter Motion round the *Earth*: But in the Quadratures ſhe goes ſlower.

Thirdly, According to the different Diſtance of the *Moon* from the *Syzygia*, that is from Oppoſition or Conjunction, ſhe changes her Motion; and in the firſt Quarter of her Motion, that is from Conjunction to her firſt Quadrature, ſhe loſes ſomething of her ſwiftneſs; in her ſecond Quarter, from the Quadrature to her Oppoſition, ſhe encreaſes in Velocity: In her third Quarter from Oppoſition to the laſt Quadrature, ſhe again loſes of her Motion; and from that Quadrature to the Conjunction, ſhe again recovers

Lecture X. her ſwiftneſs. This Inequality in the *Moon*'s Motions was firſt diſcovered by the Noble *Tycho*, who called it the *Moon*'s *Variation*.

The Variation.

Fourthly, The *Moon* moves in an Ellipſe, whoſe *Focus* is in the Center of the *Earth*, round about which ſhe deſcribes *Area's* proportional to the Times, as the Primary *Planets* do round the *Sun*; whence the Motion of the *Moon* muſt be quickeſt in the *Perigeon*, and ſloweſt in the *Apogeon*.

The Orbit of the Moon, *and its Excentricity changeable.*

Fifthly, The very Orbit of the *Moon* is changeable, and does not always keep the ſame Figure; but its Excentricity does now and then grow greater, and now and then it diminiſhes: And it is greateſt when the Line of the *Apſides* is coincident with the *Syzygia*, or is in the Line which joins the Centers of the *Sun* and *Earth*: And the Excentricity is the leaſt when the Line of the *Apſides* cuts the other at Right Angles. The difference between the greateſt and leaſt Excentricity is ſo conſiderable, that it exceeds the half of the leaſt Excentricity.

The Apogeon *has an unequable Motion.*

Sixthly, The very *Apogeon* of the *Moon* has an unequal Motion, and ſometimes moves forward, and ſometimes backwards: when it is coincident with the *Syzygial* Line, its Motion is forward; but when it cuts that Line at Right Angles, its Motion is backwards, and its progreſs, and regreſs are no ways equal. But when the *Moon* is in her Quadratures with the *Sun*, the *Apogeon* goes but ſlowly forward, or even may ſtand ſtill, or go backwards. But when the *Moon* comes to be Oppoſite or conjoined to the *Sun*, the *Apogeon* has a quick Motion forward.

Seventhly, The Motion of the *Nodes* is not at all uniform, for when the Line of the *Nodes* coincides with the Line of the *Syzygia*, then they ſtand ſtill without any Motion; but when they cut that Line at Right Angles, they go backwards, or from *Eaſt* to *Weſt* with a conſiderably quick Motion. The moſt ſagacious *Sir* ISAAC NEWTON was the firſt, and the only Man, who

who has discovered the true Causes of all these Inequalities; and has demonstrated that they all arise according to the Laws of Mechanism, from the *Theory of Gravitation* of Matter to Matter: It is very surprising that the *Moon*, which of all the Heavenly Bodies is nearest to us, should be of such difficult Access; and that it should be so hard to find out her Ways, and the Causes of all her Irregularities.

Lecture X.

THE only equal Motion of the *Moon* is that, wherewith she turns round her *Axis* in the same time that she moves round us in her Orbit, from whence it comes to pass, that she always keeps the same Face towards us. But this very equability in Rotation, is the Cause of an apparent Inequality; that the *Moon* appears to librate about its *Axis* sometimes from the *East* to the *West*, and now and then from the *West* to the *East*; and that some Parts in the *Western* Limb or Margin of the *Moon* recede from the Center of the Disk, and sometimes they move towards it. Some of these Parts which were before visible, set and hide themselves in the invisible side of the *Moon*, and afterwards become again conspicuous. Such a Motion in the *Moon* is called her *Libration*, and it arises from the unequal Motion of the *Moon* in the Perimeter of her Orbit: For if the *Moon* moved in a Circle, whose Center coincided with the Center of the *Earth*, and turned round its *Axis* in the precise time of its Period round the *Earth*; in that case the Plane of the same *Lunar* Meridian would always pass thro' the *Earth*; and the same Face of the *Moon* would be constantly and exactly turned towards us. But since the real Motion of the *Moon* is in an Ellipse, in whose *Focus* is the *Earth*, and the Motion of the *Moon* about her *Axis* is equable; or which is the same thing, every Meridian of the *Moon* by this Rotation describes Angles proportional to the Times, the Plane of no one Meridian will constantly pass thro' the *Earth*.

The Moon *moves uniformly about her* Axis.

The Moon's Libration.

Lecture X.

Plate VI. Fig. 2.

FOR let ALP be the Orbit of the *Moon*, in whofe *Focus* is the *Earth* in T, and when the *Moon* is in A, its Meridian MN produced will pafs thro' the *Earth*: And if the *Moon* only revolved in her Orbit, without any Motion round an *Axis*, the fame Meridian MN would always keep a Pofition parallel to it felf; fo that when the *Moon* comes to L, the Meridian MN would be in the Pofition PQ which is parallel to MN, but on the account of the *equable Rotation*, the Meridian MN changes its Situation, and defcribes Angles proportional to the Times; fo that in the Periodical time of the *Moon*'s Revolution round the *Earth*, it defcribes four Right Angles; and therefore in L it will have the Pofition mLn; fuch that the Angle QLn may have the fame proportion to a Right Angle, as the Time the *Moon* takes to defcribe the Arch AL, has to a fourth part of the Periodical time. But the time the *Moon* takes to defcribe the Arch AL, is to the fourth part of the Periodical time, as the *Area* ATL is to the *Area* ACL, that is to $\frac{1}{4}$ part of the *Area* of the Ellipfe: Therefore the Angle QLn will be to a Right Angle in the fame proportion. But the *Area* ATL is greater than the *Area* ACL, or than the fourth part of the *Area* of the Ellipfe: The Angle therefore QLn will be bigger than a Right, or bigger than QLC; but QLC is bigger than QLT, wherefore QLN will be much bigger than QLT. The Meridian therefore MN, whofe Plane paffed thro' the *Earth*, when the *Moon* was in A, now the *Moon* is arrived at L, does not look towards the *Earth*: And therefore the Hemifphere of the *Moon* which is towards the *Earth*, the *Moon* being at L, is not the fame with that which was towards the *Earth* when the *Moon* was in A; and thofe Parts of the *Moon*'s Surface beyond Q, will come under Obfervation, which before, when the *Moon* was in A, were not to be feen, being in the fide of the *Moon* quite oppofite to us. But as foon as the

Moon

Moon arrives at her *Perigeon* P, then the Meridian MN has deſcribed in its Rotation a Semicircle; and then again its Plane paſſes thro' the *Earth*, and the former Point N will be directly towards us, and be in the Center of the Disk. Hence it is evident that this *Libration* of the *Moon* is reſtored twice in each Period of the *Moon*, that is when ſhe comes to her *Apogeon* and *Perigeon*.

Lecture X.

IF the Surface of the *Moon* were ſmooth and poliſhed like a Looking Glaſs, it would not then reflect Light upon all ſides and every way; but it would ſhew us only in ſome Poſitions the Image of the *Sun*, no bigger than a Point, but with an immenſe Luſtre. But as in all our *Earthly* Bodies, ſo in the *Moon*, its Surface is very rough and uneven; upon which account it diffuſes the Light by reflecting it to all ſides, without producing any Image of the *Sun*, as poliſhed Glaſſes do.

The Surface of the Moon *Rugged and Mountanous*

BUT the Surface of the *Moon* is not only rough and uneven, but there are upon it moſt prodigious high Mountains, and deep Vallies, which cover the whole Face of the *Moon*: This we thus prove. If there were no Parts in the *Moon* higher than the reſt, no Prominent Points, then a Right Line in the *Dichotomy* or Quadrature, and an Elliptick Line in all the other *Phaſes* would terminate the light and dark parts of the Disk: But when the *Moon* is viewed with a Teleſcope, we find that there is no regular Line which ſeparates Light and Darkneſs in the *Moon*'s Surface, but the Confines of theſe Parts appear as it were toothed, and cut with innumerable Notches and Breaks; and even in the dark Part, near the Borders of the lucid Surface, there are ſeen ſome ſmall Places enlightned by the *Sun*'s Beams: And upon the fourth Day after *New Moon*, there may be perceived ſome ſhining Points, like Rocks or ſmall Iſlands, within the dark Body of the *Moon*; but not far from the Confines of Light and Darkneſs, there are obſerved other little Spaces which join to the enlightned

A Demonſtration that there are Mountains in the Moon.

Lecture X.

lightned Surface, but run out into the dark ſide; which by degrees change their Figure, 'till at laſt they come wholly within the illuſtrated Face, and have no dark Parts round them: Afterwards we obſerve many more ſhining Spaces to ariſe by degrees, and to appear within the dark ſide of the *Moon*, which before they drew near to the confines of Light and Darkneſs, were inviſible; being without any Light, but wholly immerſed in the Shadow. The contrary is obſerved in the Decreaſing *Phaſes*, where the lucid Spaces which joined the illuminated Surface, by degrees recede from it; and after they are ſeparated quite from the Confines of Light and Darkneſs, remain for ſometime viſible, 'till at laſt they alſo diſappear: Now it is impoſſible that this ſhould be, unleſs theſe ſhining Points were higher than the reſt of the Surface, ſo that the light of the *Sun* may reach them.

In the Moon *large Cavities and Pits.*

THESE ſhining Points ſituated in the *Moon*'s Surface, without the Confines of the illuminated Surface, are the Tops of very high Mountains, which riſing far above the other Parts of the Surface, are ſooner reached by the *Sun*'s Beams, and remain longer in the Light, than the reſt of the Parts do which are lower. Beſides theſe, we likewiſe obſerve, even in the illuminated Face of the *Moon*, many dark and obſcure Spots, which ſeem to be only Caverns, or large Cavities; on which the *Sun* ſhining very obliquely, and touching only their upper edge with his Light, the deeper places remain without Light: but as the *Sun* riſes higher upon them, they receive more Light, and the Shadow or dark Parts grows ſmaller and ſhorter, 'till the *Sun* comes at laſt to ſhine directly upon them; and then the whole Cavity will be illuſtrated, and the Parts which were obſcure before, will then look as bright as the Tops of the Mountains. From theſe conſtant Obſervations it is plain to a demonſtration, that the *Moon*'s Face is covered with Mountains in ſome places, and that in others it is cut with deep Pits and Caverns.

THE

THE *Lunar* Mountains are much higher in proportion to the Body of the *Moon*, than any Mountain upon our Globe; for the *Geometers* can take the Height of them as easily as he can find the Measure of a Mountain upon our *Earth*: The way of finding the Height of a *Lunar* Mountain is this, Let EGD be the Hemisphere of the *Moon* illuminated by the *Sun*, and ECD the Diameter of the Circle bounding Light and Shadow, A the Top of a Hill, within the dark Part when it first begins to be illuminated. Observe with a Telescope the Proportion of the Right Line AE, or the Distance of the Point A from the lucid Surface, to the Diameter of the *Moon* ED; and because in this case the Ray of light ES touches the Globe of the *Moon*, AEC will be a Right Angle, by the 16th *Prop.* Book third of *Euclid*: And therefore having in the Triangle AEC, the two sides AE and EC, we can find out the third side AC, from which subducting BC, or EC, there will remain AB, the Height of the Mountain. *Ricciolus* affirms, that upon the fourth Day after *New Moon*, he has observed the Top of the Hill called St. *Katherin* to be illuminated, and that it was distant from the Confines of the lucid Surface, about a sixteenth part of the *Moon*'s Diameter, or an eighth part of her Semidiameter. And therefore if CE be 8, AE will be 1; and the Square of AC will be equal to the Squares of CE and EA, by *Prop.* 47, Book first of *Euclid.* Now the Square of CE being 64, and the Square of AE being 1, the Square of AC will be 65, whose Square Root is 8,062 which expresses the length of AC: From thence deducting BC = 8, there will remain AB = 0,062. So that CB or CE is therefore to AB, as 8 is to 0,062; that is, as 800 to 62: And therefore since the Semidiameter of the *Moon* is 1182 Miles; if we make the proportion as 800 to 62, so 1182 is to 9; we shall have 9 Miles for the Height of that Mountain, which is therefore three times higher than the Tops of our highest Hills on *Earth.*

Lecture X.

The Lunar Mountains higher than the Mountains of the Earth.

Plate VI. Fig. 3.

A method of Measuring them.

WHO-

Lecture X.

Great varieties to be observed in the Face of the Moon.

WHOEVER ſhall Contemplate the Face of the *Moon* with a Teleſcope, will diſcern it diſtinguiſhed with an admirable variety of Spots ſome Parts have a moſt bright Luſtre, and ſome *Philoſophers* have imagined them to be Rocks of Diamonds; others have compared them to Pearls, or ſome precious Stones: But they ſeem to be the Solid parts of high Mountains, which are endued with a quality whereby they ſtrongly reflect the Light. There are again other Places and Parts of the *Moon*'s Face, and they are not a few nor ſmall, which look dark, and of a duskiſh Colure, which the *Philoſophers* have fancied to be Seas, Lakes, and Fens: But yet we find that they cannot be Seas, nor any thing of a Liquid ſubſtance, for when they are looked at with a good Teleſcope, we find they conſiſt of an infinity of Caverns and empty Pits, whoſe Shadows fall within them; which can never be in a Sea or liquid Body. Theſe black Spots therefore cannot poſſibly be Seas: But they conſiſt of ſome darker and ſad coloured Matter, which does not reflect the Light ſo ſtrongly as the Solid and ſhining Mountains do. But even within theſe dark Spots we obſerve ſome Bodies of a brighter Light, wherewith they out-ſhine the reſt.

There are no Seas.

No Clouds.

THERE ſeems to be no Clouds nor Vapours in the *Moon*, from whence Rain may be generated: For ſuch Clouds would ſometimes cover the Face of the *Moon*, and hide ſome of its Regions from our ſight, which we never obſerve them to do: But in the *Moon* there is a conſtant Serenity, without any dark Weather; and when there are no Clouds in our Air, the *Moon* conſtantly appears with the ſame Luſtre. It is probable likewiſe that the *Moon* has no Atmoſphere to ſurround it. For the *Planets* and *Stars*, which ſometimes are ſeen very near its Limb, have not their Light refracted, as it is when it paſſes thro' our Atmoſphere.

THE

fronting page 108.

I. Senex sculp^t.

fronting page 108.

I. Senex sculpt.

Lecture XI.

The Selenographers or Astronomers who have described the Moon's *Surface.*

THE *Astronomers* have drawn the Face of the *Moon*, according as it is seen with the best Telescopes, for which we are obliged to the accurate Labours of these Famous Selenographers *Florentius Langrenus*, *John Hevelius* of *Dantzig*, *Grimaldus* and *Ricciolus*, *Italians*; who have taken particular Care to note all the shining Parts of the *Moon*'s Face, and for the better distinguishing them, they have given to each Part a proper Name. *Langrenus* and *Ricciolus* have divided the *Lunar* Regions among the *Philosophers* and *Astronomers*, and other eminent Men: But *Hevelius* fearing least the *Philosophers* should quarrel about the Division of the Lands, has spoiled them of this their Property; and gives the Parts of the *Moon* those *Geographical* Names that belong to the different Islands, Countries and Seas of our *Earth*, without any regard to Situation or Figure.

LECTURE XI.

Of the Obscurations or Eclipses *of the* Sun *and* Moon.

THERE is nothing in *Astronomy* which shews the great Sagacity of Human Understanding, and its deep Penetration, more than a clear Explication of the suddain Disappearings of the *Sun* and *Moon*, that is, of their *Eclipses*; and the accurate Predictions when they are to come to pass, which the *Astronomers* can now foretel almost to a Minute. Tho' this be the nicest and most subtle Speculation of our Science, yet it is certain and undoubtable, than

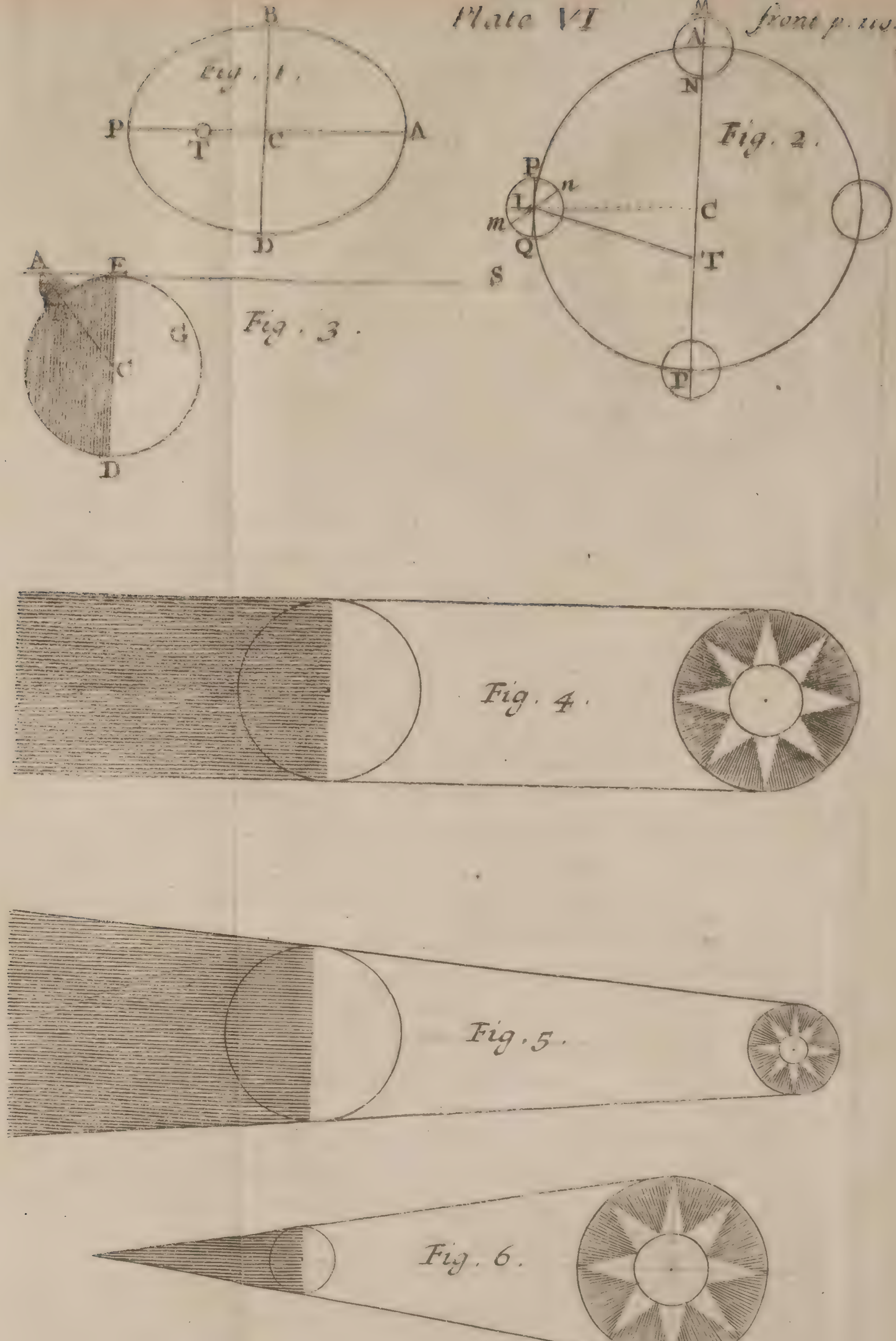
Lecture XI. which nothing can be more Sublime, or worthy of our Contemplation.

An Eclipse what. The word Eclipse is derived from the *Greek* ἐκλείπω, which signifies to Faint, or to Swoon away: So Sick and dying Persons when a swooning Fit, and a Death-like faintness comes over them, were said by the *Greeks* to fall into an Eclipse: After the same manner the *Moon*, when she Shines with a full Face, if she falls into the Shadow of the *Earth*, does lose the enlivening Beams of the *Sun*'s light, and grows Pale as if she were about to Dye. And the *Sun* again when the *Moon* interposes her Body, and deprives us of his Heat and Light; tho' in himself he retains his Lustre, yet to us he seems to vanish and grow dark. At such times the *Sun* and *Moon* are said to suffer and fall into an Eclipse. These Eclipses must be here Explained: and that we may begin from the first Principles.

A Shadow what. IT is to be observed that all Opake and dark Bodies, when they are exposed to the direct light of the *Sun*, cast a Shadow behind them, that is opposite to the Line the *Sun* is in. This Shadow is nothing but the loss or Privation of light in the Space opposite to the *Sun*, by reason the *Sun*'s Rays are intercepted by the opake Body. Now since the *Earth* is an opake Body, it must likewise cast a Shadow towards the Space opposite to the *Sun*; in which Space if the *Moon* should come, it must necessarily be darkned, and lose the Light which it had before from the *Sun*. And because the Figure of the *Earth* is Spherical, the figure of the Shadow would be Cylindrical, if the *Earth* and *Sun* were of equal bigness; or if the *Earth* were bigger than the *Sun*, the Shadow would have the figure of a Cone which had lost a peice at his Top or Vertex; and the farther it were extended, would grow thicker and thicker. Plate VI. Fig. 4, 5, 6.

The figure of the Shadow. AND in both these Cases, the Shadow would run out into infinite Space, without ever having an end: And then it would involve sometimes the other *Planets*, *Mars*, *Jupiter* and *Saturn*, within

Plate VI *front p. 115.*



in it, when they come to be oppoſite to the *Sun*, and enter within that Space: But this is never obſerved, for then theſe *Planets* would be Eclipſed: And therefore the *Sun* muſt neceſſarily be greater than the *Earth*, whoſe Shadow muſt conſequently be of a Conical Figure, and end in a Point.

Lecture XI.

The Sun *bigger than the* Earth.

BUT the *Moon*, ſince its Diameter is contained about three times in the Diameter of the Shadow, and the Diameter of the Shadow is leſs than that of the *Earth*, muſt needs be much leſs than our *Earth*.

LET S repreſent the *Sun*, T the *Earth*, and the Cone ABC the Shadow. It is evident there can be no Line drawn from the *Sun*, to any Point of the Space ABC, which does not fall upon the *Earth*: And therefore ſince the *Earth* is an opake Body, it will not ſuffer any Rays to paſs thro', or to illuſtrate the Space ABC. Now if the *Moon* when ſhe is oppoſite to the *Sun* ſhould come into this Space, ſhe muſt then be involved in Darkneſs; and would then ſuffer an Eclipſe in the very time of *Full Moon*.

Plate VI. Fig. 7.

THE *Moon* likewiſe upon the ſame account muſt have a Shadow of a Conical figure oppoſite to the *Sun*; and if this Shadow ſhould fall upon the *Earth*, which can never happen but when the *Moon* is in Conjunction with the *Sun*, the Inhabitants of the *Earth*, on whom the Shadow falls, will be involved in Darkneſs; and the *Sun* will ſeem to them to be in an Eclipſe, ſo long as the Shadow covers them: But becauſe the *Moon* is much leſs than the *Earth*, its Shadow can never cover the whole *Earth*, but only a ſmall Part of it, ſuch as BC: And within that Space only where the Shadow comes, there will be total Darkneſs; and the reſt of the circumjacent places will be illuſtrated with ſome of the *Sun*'s beams, and their Inhabitants will only ſee a part of the *Sun*'s Disk obſcured; which will be greater or leſs, according as they are nearer or further

When there can happen an Eclipſe of the Moon.

Plate VII. Fig. 1.

removed

Lecture XI.

removed from the Shadow, particularly they who live about P, will ſee half the *Sun* Eclipſed: But whoſoever lives between M and N, will ſee at the ſame time all the *Sun*'s Body, and perceive no Eclipſe.

In ſome places of the Earth *an E-clipſe may be total, in o-thers parti-al, and in o-thers none at all.*

When an Eclipſe of the Sun *hap-pens.*

HENCE it is manifeſt that there can be no Eclipſe of the *Moon* but in *Full Moons*, when ſhe is oppoſite to the *Sun*; as the Shadow always is. Nor can there be any Eclipſe of the *Sun* but in *New Moons*, when ſhe is in Conjunction with the *Sun*; for then only can ſhe caſt her Shadow on the *Earth*. Since therefore in every Month there is one *Full Moon* and one *New Moon*; it may be asked how it comes that the *Sun* and *Moon* do not ſuffer Eclipſes every Month. And indeed if the *Moon* did always move in the Plane of the Ecliptick, ſince the *Axis* of the Shadow is always in the ſame Plane, the *Moon* would then every *Full Moon* paſs thro' the Body of the Shadow, and there would be a total Eclipſe of the *Moon*. So likewiſe in every *New Moon*, if ſhe were not then too far off us, ſhe would caſt her Shadow on the *Earth*, and produce an Eclipſe of the *Sun*, in ſome or other of the Regions of the *Earth*. But the Caſe is otherwiſe, for we have ſhowed that the Plane of the *Moon*'s Orbit, does not coincide with the Plane of the Ecliptick; but that it cuts it in a Line which paſſes thro' the Center of the *Earth*: And therefore the *Moon* is never in the Plane of the Ecliptick, but when it is in this Line, which is the Interſection of the two Planes, that is, when it enters the *Nodes*. And therefore when it happens that the *Moon* at *Full*, ſhall likewiſe be in one of the *Nodes*; then the *Axis* of the Shadow will paſs thro' the Center of the *Moon*, and then ſhe will be in a Total and Central Eclipſe. Let the Circle MN repreſent the tranſverſe Section of the Shadow, at the Diſtance of the *Moon*; and the Line CD a Portion of the Orbit of the *Moon*, which the *Moon* deſcribes in the time of *Full Moon*; which becauſe it is but a ſmall Portion, may be well enough repreſented by

Plate VII. Fig. 2. *Total and central E-clipſes of the* Moon.

by a Right Line: Let the Right Line BGA, be in the Plane of the Ecliptick, and let F be the Position of the *Moon*'s Center when she first touches the Shadow, E the Position of the same Center when she first leaves it: G the same Center of the *Moon* when the *Axis* of the Shadow passes thro' it: It is evident, that such an Eclipse will be Central and Total; and there will always be such Eclipses when the Center of the *Moon* and *Axis* of the Shadow meet in the *Nodes*. Hence the Duration or time that an Eclipse can last, may be as long as the *Moon* is passing thro' an Arch, that is equal to EF, or four Diameters of the *Moon*, that is, about two Degrees, which Space the *Moon* generally moves thro' in the space of four Hours. Lecture XI.

BECAUSE of the largeness of the Diameter of the Shadow in comparison of that of the *Moon*, there may be Total Eclipses which are not central, where the *Node* does not coincide with the *Axis*, and may even lye without the Shadow, as the Figure sufficiently shews. The *Node* may likewise be at such a distance from the Shadow, that there may be only a part of the *Moon*'s Body that can enter it, and then we shall have a Partial Eclipse of the *Moon*, as is manifest by the Figures: and these Partial Eclipses will be greater or less, according as the distance of the *Node* from the Shadow is less or greater. But when it happens that the *Node*, in the time of *Full Moon*, is further removed from the *Axis* of the Shadow than Twelve Degrees, the *Moon* then will have so much Latitude, or its distance from the Ecliptick will be so great, that it cannot be obscured by the Shadow. Plate VII. Fig. 3. *Partial Eclipses.* Plate VII. Fig. 4, 5.

AS the Shadow of the *Earth* cast upon the *Moon* produces an Eclipse of the *Moon*, so if the Shadow of the *Moon* should fall upon the *Earth*, it will cause an Eclipse of the *Earth*, at least on that part of the *Earth* on which the *Eclipses of the* Earth.

Lecture XI.

Shadow falls. For the *Moon* being much leſs than the *Earth*, cannot with its Shadow involve the whole Disk of the *Earth*, but only a very ſmall part of it; and ſo all the Eclipſes of the *Earth* will be Partial and not Total; and ſuch Eclipſes will only produce a darkneſs upon thoſe places where the Shadow falls, and the Inhabitants within this Shadow will only ſee the *Sun* Totally darkned, and therefore they will call them Eclipſes of the *Sun*: but this is improperly attributed to the *Sun*, who all the time retains his Light without the leaſt diminution; and it is only thoſe Inhabitants of the *Earth* that are under the Shadow, that are truly Eclipſed and involved in Darkneſs.

THAT we may deſcend more particularly to explain the Phænomena, or Appearances of Eclipſes; it will be requiſite to ſhew the Method of Meaſuring the dimenſions of the Conical Shadows of both *Earth* and *Moon*: For which purpoſe we will firſt lay down the following *Poſtulatum*. If from the Center of the *Sun*, there be drawn Right Lines to every Point of the *Earth*, or to as many as you pleaſe, theſe Lines may all of them be eſteemed as Parallel. For Parallel Lines are ſuch as do not meet till they are produced to an Infinite diſtance; and therefore ſuch Lines as do not meet but at a diſtance immenſly great, in compariſon of the diſtance of the Lines from one another, are nearly, or as we may ſay Phyſically Parallel; that is to ſay, they will have the ſame effect in Nature, and the Phyſical Obſervations that are to be made from them, will be the ſame as if the Lines were abſolutely Parallel. Now the diſtance of the *Earth* from the *Sun* is ſo great, that the Diameter of the *Earth* compared with it, is but as a Point, as is now acknowledged by all Mathematicians; for this Diameter ſeen from the *Sun* does appear under an unperceptible Angle, or which is ſo ſmall that the Eye cannot obſerve it, and the

Lines drawn from the Center of the Sun *to any Point of the* Earth, *may be reckoned as Parallel.*

the Earth appears only like a Point: And therefore in comparison of the great distance of the *Sun* it vanishes, and consequently Lines drawn from the Center of the *Sun* to different parts of the *Earth*, will be at least Physically Parallel. Moreover it is known in Geometry, that if a Right Line falls upon two other Right Lines, so as to make the two internal Angles on the same side equal to two Right Angles, that these two Lines on which it falls are Parallel, by 29 *Prop.* Book first of *Euclide.* Let therefore the Line A B be the Diameter or Semidiameter of the *Earth*, and C the Center of the *Sun*: drawing A C and B C, the Angles A, B and C of the Triangle A B C are equal to two right Angles: Now the Angle C at the *Sun* vanishes, and is next to nothing, for the *Earth* seen from the *Sun* looks like a Point; and therefore the Angles at A and B must make by themselves two Right Angles very nearly, and therefore the Right Lines A C, B C, are nearly Parallel. It is upon the same account that if there be taken two Threads with Plummets to make them hang perpendicularly, the Directions of those Threads are by all Artificers esteemed as Parallel, tho' their directions will meet at the Center of the *Earth*, to which all heavy Bodies have a *Tendency*, or *Propension*.

Plate VIII. Fig. 6.

WHAT we have said in this case concerning the *Earth*, is also true of the *Moon*, for its Diameter has a much less proportion to the distance of the *Sun*, than that of the *Earth* has to it. And not only Lines drawn from the *Sun* to any Points of the *Earth* and *Moon*, are to be reputed Parallel; but if there be two Lines drawn, one from the Center of the *Sun* to the *Earth*, the other from thence to the *Moon*, these may be likewise taken as Parallels, for they will not sensibly differ from a Parallelism, especially in the time of Eclipses: the difference of these Lines from real Parallels

Lecture XI. is so small, that it will make no sensible error in the Calculation of Eclipses.

WE likewise premise the following *Lemma*, which is easily demonstrated.

Plate VII. Fig. 7. A Lemma.

IF two Right Lines AE BF *touch a Circle, and there be drawn from the Points of Contact to the Center the Lines* AD BD; *the Angle at the Center contain'd under these Lines, will be equal to the Angle that the Tangents make with one another.* For in the Four-sided Figure GADB, all the Angles make four Rights: But the Angles A and B make two Rights, by the 18 *Prop.* Book third of *Euclide*: Wherefore the Angles AGB and D, are equal to two Rights. But by the 13 *Prop.* Book first of *Euclid*, the Angles AGB and EGB, are equal to two Right Angles, and therefore the Angles D and EGB are equal, since the Angle AGB makes two Right Angles with either of them.

The Dimension of the Angle of the Conical Shadow. Plate VII. Fig. 8.

LET the Circle ABK represent the Globe of the *Earth*, AM the Line which joins the Centers of the *Sun* and *Earth*; to which let the Diameter CB be perpendicular: if from B there be drawn to the Center of the *Sun* the Line EF, this Line will be Parallel to the Line CM, as has been shown: Make the Angle BCD equal to the Apparent Semidiameter of the *Sun*, that is, equal to the Angle under which the Semidiameter of the *Sun* is seen from the *Earth*, and then thro' D draw the Tangent DG. By the *Lemma* above demonstrated, the Angle GEF will be equal to the Angle BCD, or to the Apparent Semidiameter of the *Sun*; and therefore since the Line BF produced goes to the Center of the *Sun*, the Line GED must touch its Circumference, and it will also touch the *Earth*, and being produced, will meet with the *Axis* of the Shadow CH in H, so that the Angle DHC, will be half the Angle of the Conical Shadow. Now because EF is Parallel to MH, the Angles DHC and GEF are equal, by the 29 *Prop.*

Prop. Book firſt of *Euclid.* But GEF is equal, as has been ſhewed, to the Apparent Semidiameter of the *Sun*; wherefore the whole Conical Angle KHD, is equal to the Apparent Diameter of the *Sun.*

THE ſame thing is to be demonſtrated of the *Moon*, and Univerſally, the *Sun*'s Apparent Diameter remaining the ſame in all Spheres, which are not bigger than the *Earth*, the Angles of the Conical Figures which include the Shadows are all equal, and all their Shadows will be Semilar Figures. This may likewiſe be demonſtrated in this manner.

Theſe Angles in all Conical Shadows are equal.

LET AGF be the *Sun*, DHE the *Earth*, SC a Line joining the Centers of the *Sun* and *Earth*, AD a Right Line which touches both Bodies; and let the Lines AD SC produced meet in M, the Angle AMS will be half the Angle of the Shadowed Cone. Now in the Triangle SDM, the outward Angle ADS is equal to both the inward and oppoſite Angles, by *Prop.* 32 Book firſt of *Euclid*; that is, the Angles DMS and DSM are equal to the Angle ADS: but the Angle DSM is nothing, or next to nothing, being the Angle under which the Semidiameter of the *Earth* appears as ſeen from the *Sun*, and the Angle ADS is the Apparent Semidiameter of the *Sun*; therefore the Angle DMS or the Semiangle of the Cone, is equal to the Apparent Semidiameter of the *Sun.*

Plate VII Fig. 9.

LECTURE XII.

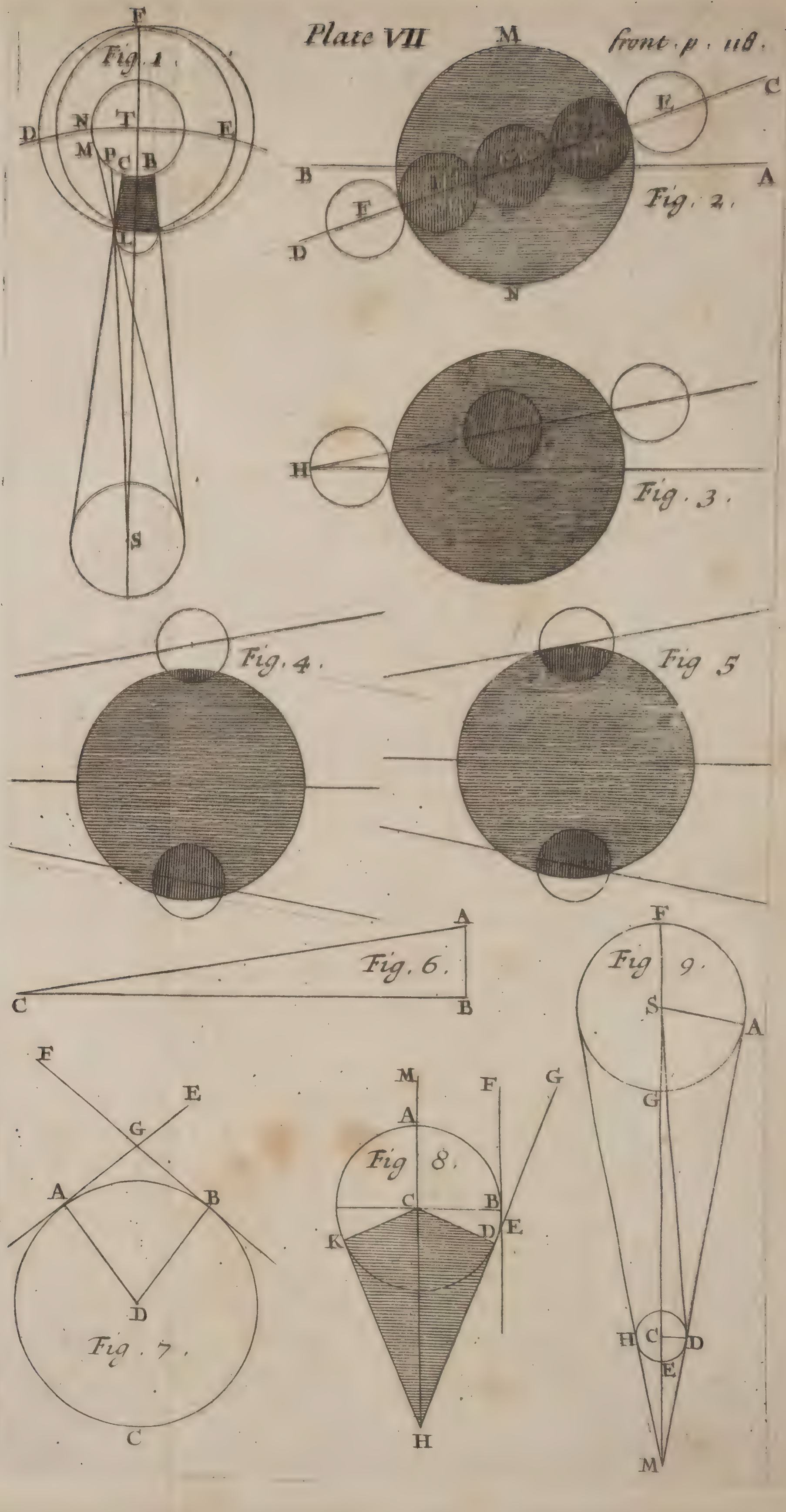
Of the Penumbra *and its Cone, the Height of the Shadow, and the Apparent Diameters of the Shadows.*

BESIDES the Shadow which is deprived of all the *Sun*'s Light, there is a certain Space which is but a Partial Shadow and is called a *Penumbra*; for tho' all the *Sun*'s Body does not illuminate it, there are for all that Rays coming from ſome part of the *Sun*, which doe enter it, and render it lucid, the reſt of the *Sun*'s Beams being intercepted by the Opake Body of the *Earth:* and the parts of this *Penumbra* will have different Degrees of Illumination, according as they are nearer or further removed from the Shadow. The Space of the *Penumbra* is to be determined in this manner.

Plate VIII. Fig. 1. LET the Circle AEFG repreſent the *Sun*, HED any Opake Sphere, for Example the *Moon*, it being her *Penumbra* that we are at preſent concerned with; SC the Line which joins the Centers of both Spheres. Draw the Line FDO, touching the Left ſide of the *Sun* and the Right ſide of the *Moon*, and the Line AHP, which touches the Right ſide of the *Sun* and the Left of the *Moon*: let theſe two Lines cut the Line SC in I. The Point I remaining immoveable, either of the Right Lines IDO, or IHP being extended indefinitely, let them be turned round the *Axis* IM, with a Conical Motion, ſo that they may always touch the Globe

Plate VII

front. p. 118.



Globe of the *Moon*; there will by that means be generated an indefinite Conical Surface, including both the Shadow and the Circumambient Space ODM PHM; into which Space some Rays of the *Sun* are hindred from entering by the Opake Body of the *Moon*: And this is the Space which we call the *Penumbra*, which is darker in X or Y, which are nearer the Borders of the Shadow, than in V and N, which are nearer the Conical Surface. For the places X and Y are illustrated with a smaller Portion of the *Sun*'s Disk, than the other places further distant from the *Axis* of the Cone. Now if the *Earth* come within this Space, a certain Portion of its Surface at S may be included in the Total Darkness, and the Inhabitants of that Region will see a Total Eclipse of the *Sun*; but those who live without this Shadow, but are still within the *Penumbral* Space, as about Q and X, will have no Total Darkness, some part of the *Sun*'s Disk being still visible, while the rest is hid by the *Moon*. For let us draw from Q the Line QD, touching the Globe of the *Moon*, which being produced to the *Sun*, the Point Q being immoveable, if the Line QD indefinitely extended be moved by a Conical Motion round the *Moon*, the Conical Surface it describes, will cut off a Portion of the *Sun*'s Disk, which is covered by the *Moon*.

Lecture XII.

WE find the Dimensions of the Cone of the *Penumbra* in this manner. Let the Circle HDL represent the Opake Sphere of the *Moon*, SC the Line joining its Center with the Center of the *Sun*; and let CB the Semidiameter of the *Moon* be Perpendicular to CS, and BF Parallel to it touching the *Moon* in B. Make the Angle BCD equal to the Apparent Semidiameter of the *Sun*, and thro' D draw DG a Tangent to the *Moon*. And by the *Lemma* premised, the Angle FEG will be equal to the Angle BCD, or to the Apparent Semidiameter of the *Sun*; and

Plate VIII. Fig. 2. *The dimensions of the Conical* Penumbra.

Lecture XII. and therefore ſince the Line E F goes to the Center of the *Sun*, the Line E D G muſt touch the Inferior Limb of the *Sun*: but it alſo touches the *Moon*; and therefore the Point of this Line being immoveable, if it be carried by a Conical Motion round the *Moon*, it will generate the Surface which includes the *Penumbra*. And becauſe of the Parallels E F, C S, the alternate Angles F E I and E I C will be equal; but the Angle E I C is the Semiangle of the Cone, and F E I is the Apparent Semidiameter of the *Sun*; and therefore half the Angle of the *Penumbral* Cone, is always equal to the Apparent Semidiameter of the *Sun*. The Cone therefore of the Total Shadow, and that part of the *Pennmbral* Cone which lies between the *Sun* and the *Moon*, are equal and ſimilar Figures; for they have their Vertical Angles and Baſes equal.

Plate VIII. Fig. 3. THE Height of the Shadow of the *Earth* is thus determined. Let C T be the Semidiameter of the *Earth*, T M the height of the Cone or Shadow: If T M be the Radius, C T will be the Sine of the Angle T M C, which is half the Angle of the Cone. And this Angle is equal to the Apparent Semidiameter of the *Sun* as has been ſhewed, and in the mean diſtance of the *Sun*, is about 16 Minutes. Let therefore the Sine of 16 Minutes be to the Radius, as the Semidiameter of the *Earth* to a fourth, and we ſhall find T M equal to 214,8 Semidiameters of the *Earth*: But when the *Sun* is at his greateſt diſtance, half the Angle of the Cone is 15 Minutes and 50 Seconds, and the Height of the Shadow becomes 217 Semidiameters of the *Earth*: and ſince the Diameter of the *Earth* is to the Diameter of the *Moon*, as 100 is to 28; the Altitude of the *Earth*'s Shadow, will be to the Altitude of the *Moon*'s in the ſame Proportion, for the Conical Shadows are ſimilar Figures; and therefore the Height of the *Moon*'s Shadow will be 59,36 Semi-

The height of the Earth's *Shadow.*

The height of the Moon's *Shadow.*

Semidiameters of the *Earth*: Hence, if the distance of the *Moon* from the *Earth* be greater than her mean diſtance, which is about 60 Semidiameters of the *Earth*, the Shadow of the *Moon* cannot reach the *Earth*, in which caſe there may be a Central Eclipſe of the *Sun* but not a Total one: But round the *Moon* there will appear part of the *Sun*'s Body, in the form of a Luminous Circle, which like a bright ſhining Ring of Gold, will embrace the Body of the *Moon*. It alſo follows, that if in the time of the Eclipſe, the Anomaly of the *Moon* be leſs than three Signs, or bigger than nine Signs, there can no where be a Total Eclipſe of the *Sun*, for in all theſe Degrees of Anomaly, the diſtance of the *Moon* is greater than her mean diſtance. Lecture XII.

The Portion of the Earth's *Surface that may be involved in the Shadow.*

TO find how much of the *Earth*'s Surface can be involved in the *Moon*'s Shadow in the time of an Eclipſe, when it directly falls upon it: Let us ſuppoſe the diſtance of the *Sun* to be the greateſt that can be, in which caſe the height of the Conical Shadow of the *Moon* is about 60 Semidiameters of the *Earth*: Let us likewiſe ſuppoſe the diſtance of the *Moon* from us to be the leaſt that can be, that the *Earth* may receive the moſt of the Shadow. This leaſt diſtance of the *Moon* from the *Earth* is about 56 Semidiameters of the *Earth*: Now let L repreſent the *Moon*, and T the Center of the *Earth*, L T the diſtance of the *Moon* from the *Earth*, which is equal to 56 Semidiameters; and ſince I M is 60, T M muſt be four Semidiameters, and T B will be to T M as 1 to 4. But as T B is to T M, ſo is the Sine of the Angle T M B, which is 15′ 50″, to the Sine of the Angle T B M; by which means we find the Angle T B M to be 63 Minutes and 10 Seconds. But the Angle A T B is equal to both T M B and T B M, by 32 *Prop.* Book 1ſt. of *Euclid*, and therefore the Angle A T B is 79 Minutes, and ſuch is the Arch A B; the double Plate VIII. Fig. 4.

of

Lecture XII. of which is the Arch B C equal to 158 Minutes, or to 180 English Miles. We have here supposed the *Axis* of the shade to pass thro' the Center of the *Earth*; which it does when the Centers of the *Sun*, *Earth* and *Moon* are in the same Right Line precisely: but when the three Centers do not lye in the same Right Line, the Conical Shade is cut obliquely, and the Figure of it upon the *Earth* is Oval, whose Diameter is easily to be determined by the distance of the *Moon* from the *Sun* seen from the Center of the *Earth*.

How much of the Surface may be included in the Peunmbra.
Plate VIII. Fig. 5.

IF we inquire how much of the Surface of the *Earth* can be involved in the *Penumbra*; it may be found by this means: Let us suppose the Apparent Diameter of the *Sun* to be the greatest, which is when the *Earth* is in her *Perihelion*, and is about 16′ 23″. Let A B D be the *Earth*, L the *Moon*, and A M B be half the Angle of the Cone, which is likewise 16′ 23″: By which we shall find the height of it L M, equal to 58 and a half Semidiameters of the *Earth*: Let the *Moon* be in her *Apogeon*; and therefore at her greatest distance from the *Earth*, which is 64 Semidiameters of the *Earth*; and T M is equal to both T L and L M, that is to $122\frac{1}{2}$ Semidiameters: but by a Trigonometrical Theorem, T B is to T M, as the Sine of the Angle T M B is to the Sine of the Angle M B N or M B T. But T B is to T M as 1 is to $122\frac{1}{2}$, and the Angle T M B is 16 Minutes 23 seconds, and therefore we shall find out the Angle M B N to be 35 Degrees and 42 Minutes, which Angle is equal to both the Angles T M B and M T B. If therefore from the Angle M B N 35 Degrees 42 Minutes, we Substract the Angle T M B, there will remain the Angle M T B 35 Degrees 25 Minutes, which is the measure of the Arch A B; whose double 70 Degrees and 50 Minutes, is equal to the Arch C A B which makes about 4900 English Miles.

IF the Conical Shadow of the *Earth* at the distance of the *Moon*, be cut with a Plane

Perpendicular

Perpendicular to its *Axis*, the Section will be a Circle, which is called the Shadow, whose Apparent Diameter seen from the Center of the *Earth*, is thus determined. Let T be the Center of the *Earth*, C M T half the Angle of the Cone, F L H the Section whose Diameter is F H. Having the Angle of the Cone, we by that means can find its Altitude T M; but we have also T L, the distance of the *Moon* from the *Earth*, and therefore we can find M L; but we have also the Angle F M L, therefore we can find out F G half the Diameter of the Shadow at the distance of the *Moon*: and therefore in the rectangled Triangle F T G, having the two sides F G and T G, we can find by Trigonometry the Angle F T G, the apparent semidiameter of the Shadow seen from the Center of the *Earth*. It may likewise be thus found; having F T the distance of the *Moon* from the *Earth*, and C T the Semidiameter of the *Earth*; in the Triangle C F T, we may find out the Angle C F T, which is equal to the two Angles F M T and F T M: if therefore we substract the Angle F M T, which is half the Angle of the Cone, from the Angle C F T, we shall find the Angle FTM or FTL: The Angle CFT is the Apparent Semidiameter of the *Earth* seen from the *Moon*, and is called the *Horizontal Parallax* of the *Moon*, the reason of which we shall shew when we come to treat about *Parallaxes*. These Apparent Semidiameters of the *Earth*, or *Horizontal Parallaxes* of the *Moon*, constantly vary as the distance of the *Moon* does, and they are found ready Calculated in all *Astronomical* Tables.

Lecture XII.

The Apparent Diameter of the Shadow of the Earth *at the distance of the* Moon *determined.*

Plate VIII. Fig. 3.

Another way of finding the same.

The Horizontal Parallax *of the* Moon.

LET ☊ M be a Portion of a Line in the Plane of the Ecliptick, ☊ L a Portion of the Lunar Orbit, which the *Moon* moves through, about the time of *Full Moon*, which because it is small, may be represented by a Right Line. Let the Circle F M O represent the Shadow of the *Earth* at the distance of the *Moon*, and its Center G; G L is the Latitude of the *Moon* in the time

Plate VIII. Fig. 6.

Lecture XII. time of *Full Moon*, which is almoſt equal to the ſhorteſt diſtance of the *Moon* from the Plane of the Ecliptick. It is manifeſt that if G L the Latitude of the *Moon*, be greater than the ſum of the Semidiameters of the *Moon* and Shadow; then the *Moon* will no part of it enter into the Shadow. But if the Latitude of the *Moon* be juſt equal to theſe two Semidiameters, than the Limb of the *Moon* will juſt touch the Shadow, but not enter it: But if the Latitude of the *Moon* be leſs than this ſum, but greater than their difference, there will be a Partial Eclipſe; and if the Latitude of the *Moon* be leſs than the difference of the Semidiameters of the *Moon* and Shadow, the Eclipſe will be Total: And by this means we can find out the Ecliptick Terms or *Limits*, which are ſuch that if the diſtance of the *Moon* from the *Node* be leſs than they are, in the time of *Full Moon* there will be an Eclipſe: If greater there can be no Eclipſe. Let ☊ S repreſent a Portion of a Line in the Plane of the Ecliptick Parallel to the *Earth*'s Orbit, ☊ L a Portion of the *Moon*'s Orbit, S L the Latitude of the *Moon* when at *Full*; and let us ſuppoſe this Latitude to be ſuch, that the Margin of the *Moon* may juſt touch the Shadow, and let the *Node* be at ☊. The Angle L ☊ S is the inclination of the Orbit of the *Moon* to the Plane of the Ecliptick, which is five Degrees; and L S the Latitude of the *Moon*, when its Limb touches the Shadow, equal to 66 Minutes; and therefore in the rectangular Triangle ☊ L S, having L S and the Angle L ☊ S, we can find ☊ S, the diſtance of the *Node* from the Point of the Ecliptick oppoſite to the *Sun*, which is 754 Minutes or 12 Degrees 34 Min. And if in the time of *Full Moon*, the *Moon*'s place in the Ecliptick be further diſtant from the *Node* than 12 Degrees 34 Minutes, there can then be no Eclipſe of the *Moon*.

Plate IX. Fig. 1, 2.

The Limits *of Eclipſes.*

Plate IX. Fig. 3.

The Limits *determined.*

LET L be the Center of the *Moon*, whoſe Conical Shadow is D M E. Imagine this Shadow

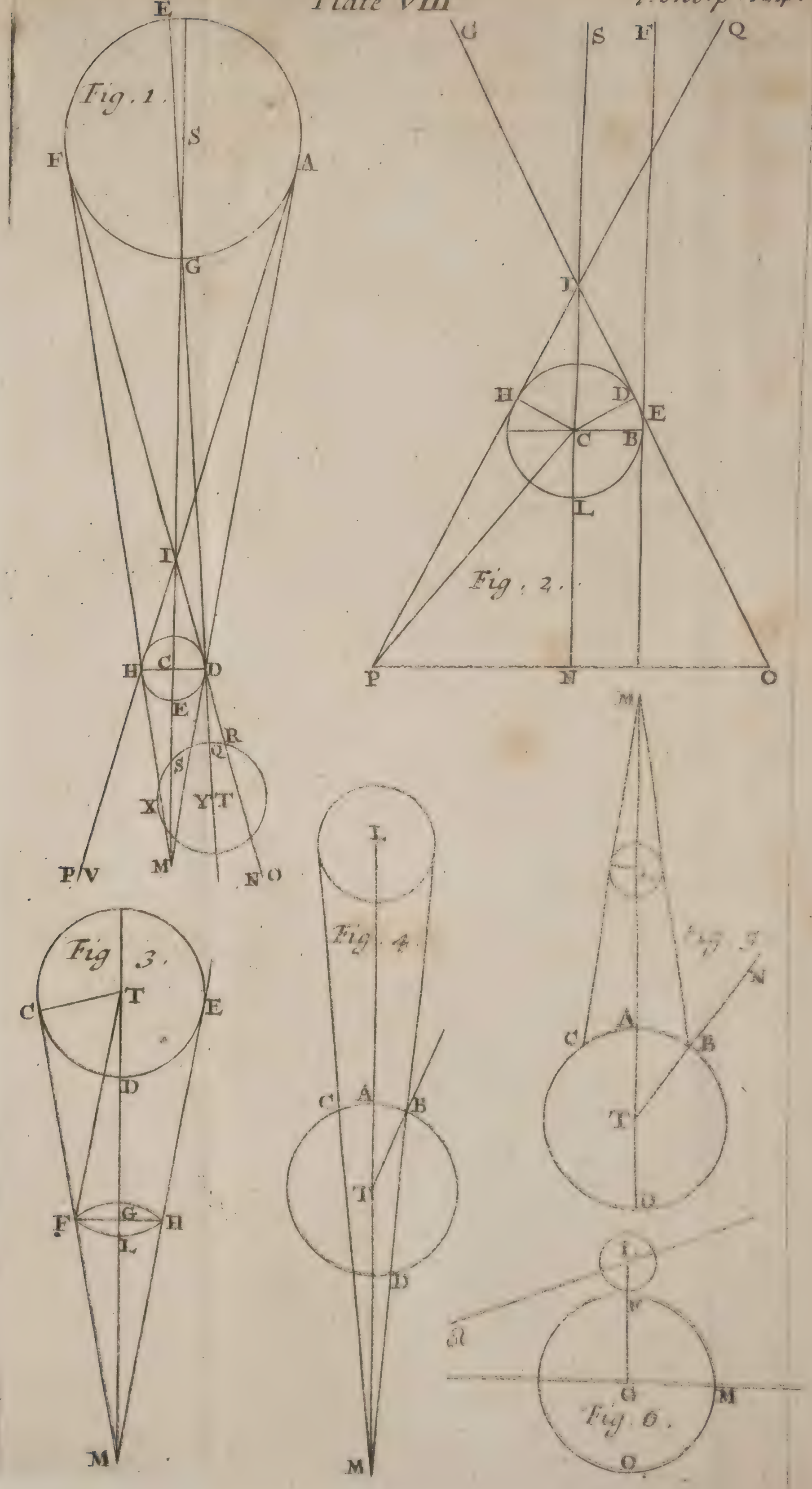


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.

dow cut at the diſtance of the *Earth* with a Plane perpendicular to its *Axis*; the Section will be a Circle, whoſe Semidiameter T P is called the Semidiameter of the *Moon*'s Shade: Now the Angle under which this Semidiameter appears ſeen out of the *Moon*, is equal to the difference of the Semidiameters of the *Sun* and *Moon* ſeen from the *Earth*: For the Angle L P D is the Apparent Semidiameter of the *Moon* ſeen from the *Earth*, which is equal to the two internal Angles P M L and P L M; and therefore if we ſubſtract from the Angle L P D, which is the Apparent Semidiameter of the *Moon*, the Angle P M L which is equal to the Apparent Semidiameter of the *Sun*, there will remain the Angle P L T, the Apparent Semidiameter of the Shadow ſeen from the *Moon*.

Lecture XII.

Plate IX. Fig. 4.

The Diameter of the Moon's *ſhadow at the* Earth *when ſeen from the* Moon.

AGAIN, let L be the Center of the *Moon*, A M B the *Penumbral* Cone of the *Moon* extended as far as the *Earth*, and its *Axis* M T; if this Cone at the diſtance of the *Earth* be cut by a Plane tranſverſely, the Section will be a Circle whoſe Semidiameter is A T, and is called the *Semidiameter of the Penumbra*. And the Angle under which it appears from the *Moon* is the Angle T L A, which is the external Angle of the Triangle L M A, and is equal to both the inward Angles L A M and LMA. But the Angle LMA is half the Angle of the Cone, which is the ſame with the apparent Semidiameter of the *Sun*, and M A L or C A L is equal to the apparent Semidiameter of the *Moon* ſeen from the *Earth*; and therefore the Apparent Semidiameter of the *Penumbra* ſeen from the *Moon*, is equal to the ſum of the Semidiameters of both *Sun* and *Moon*.

Plate IX. Fig. 5.

The Apparent Diameter of the Penumbra.

IF the *Sun* had no Apparent Motion ariſing from the real Motion of the *Earth*, the way of the *Moon* from the *Sun* would be the ſame with her real way in her Orbit. But becauſe while the *Moon* is proceeding in her Orbit, the *Sun* alſo ſeems to move in the Eclipticke, the way

The way of the Moon *from the* Sun.

Lecture XI.

Plate IX. Fig. 6.

way the *Moon* moves towards or from the *Sun*, will be different from that which ſhe has in her Orbit, and its inclination to the Ecliptick will be greater than the inclination of the Orbit to it. Let ☊ A be a Portion of the *Moon*'s Orbit produced to the Ecliptick: And ſuppoſe the *Sun* and *Moon* in Conjunction in the *Node*: Now then while the *Moon* in her Orbit deſcribes the Space ☊ L, the *Sun* by his Apparent Motion will deſcribe the Space ☊ S in the Ecliptick, and S L will be the way of the *Moon* from the *Sun*. Now if two Bodies be both moved the ſame way, but one faſter than the other, their relative Motion whereby the one recedes from the other, is the ſame as if the ſloweſt Body ſtood ſtill and the other moved on with the difference of Velocities, as we have demonſtrated in our Phyſical Lectures. Thro' the place of the *Moon* L, draw B L Parallel to the Ecliptick, to which let ☊ B be Perpendicular. Now while the *Moon* in her Orbit deſcribes the Space ☊ L, its Motion according to the Ecliptick is equal to the Space B L; take L *l* equal to ☊ S, and draw ☊ *l*, it will be Parallel to S L; and the Motion of the *Moon* from the *Sun* will be the ſame as if the *Sun* had remained in the *Node*, and the *Moon*, according to the Ecliptick, had been carried with the Velocity B *l*, which is the difference of the Velocities of the *Sun* and *Moon*, according to the Ecliptick. Becauſe the Angles B L ☊ and B *l* ☊ are but ſmall, the Angle B L ☊ will be to the Angle B *l* ☊, as B *l* is to B L, that is, as the difference of the Motions of the *Sun* and *Moon* according to the Ecliptick, is to the Motion of the *Moon* in the Ecliptick, ſo will the Angle which the Orbit of the *Moon* makes with the Ecliptick be to the Angle B *l* ☊, which is equal to the Angle LSE, or the Inclination of the way of the *Moon* from the *Sun* to the Ecliptick: And by this means we can find out the Angle which a Circle of Latitude drawn thro' any Point of the Ecliptick

fronting p. 126.

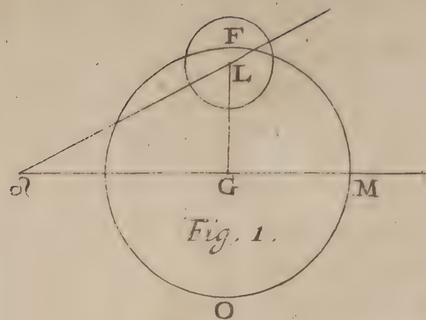


Fig. 1.

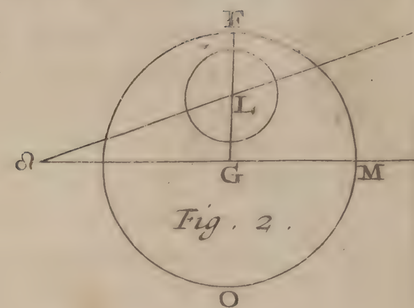


Fig. 2.

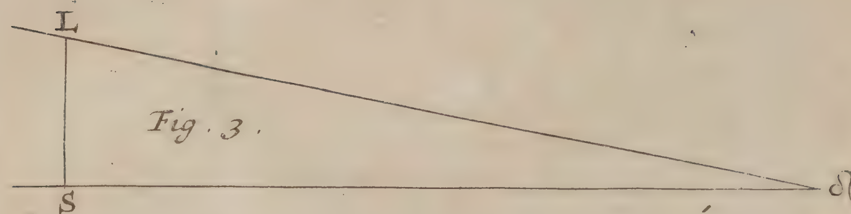


Fig. 3.

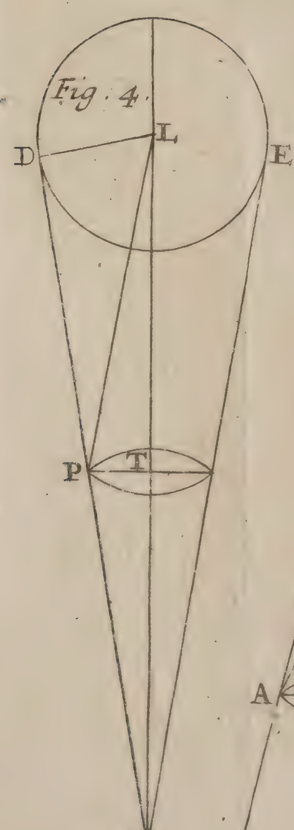


Fig. 4.

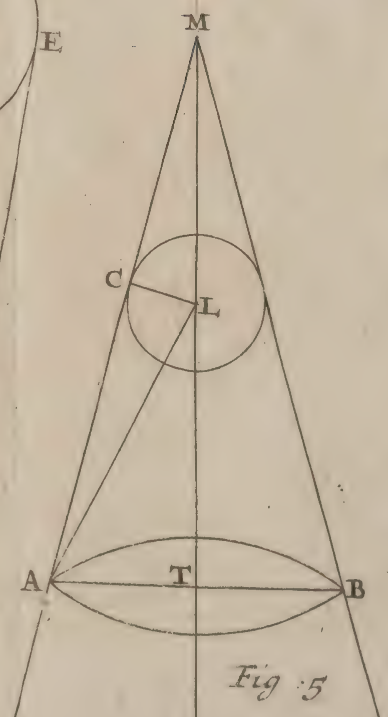


Fig. 5

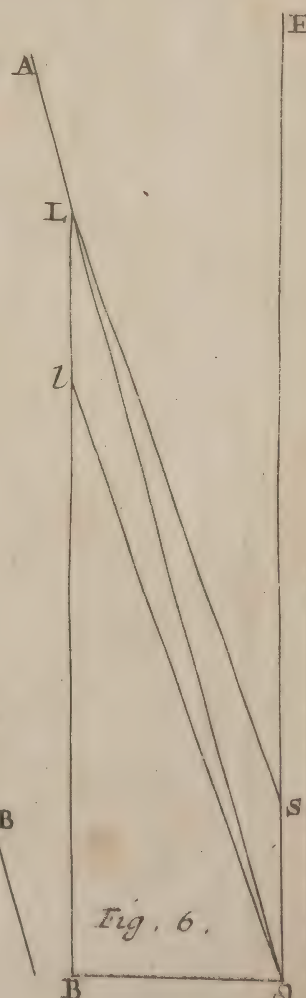


Fig. 6.

tick makes with the way of the *Moon* from the *Sun*. For in the rectangular Spherical Triangle which the Ecliptick, the Circle of Latitude and the way of the *Moon* from the *Sun* do form, we have one Angle which is the Inclination of the way of the *Moon* from the *Sun* to the Ecliptick, and its Base which is the distance of the Circle of Latitude from the *Node*, and therefore we can find the other Acute Angle. Lecture XIII.

LECTURE XIII.

Of the Projection of the Moon's *Shadow on the Disk of the* Earth.

IF a Right Line be Projected on a Plane that is Parallel to it, by letting fall from all its Points Perpendiculars on the Plane, the Projection, or the place where all Perpendiculars meet with the Plane, will be a Right Line, Parallel and equal to the former Line which was Projected. For the Perpendiculars that fall from the extremities of the Right Line are Parallel and equal, and therefore the Lines which join them will be Parallel and equal.

HENCE if two Right Lines touching one another be Parallel to any Plane, the Projections of these two Lines upon that Plane will contain an Angle equal to the Angle the Lines themselves make together, this is plain by *Prop.* 10 Book XI of *Euclid.* Hence all Plane Figures projected on a Plane Parallel to themselves have for

Lecture XIII. for their Projections Figures exactly ſimilar and equal to themſelves.

Plate X. Fig. I. BUT if a Line be inclined to any Plane, its Projection upon that Plane made by letting fall from it Perpendiculars to the Plane, will be to the Line it ſelf, as the Coſine of the Inclination of the Line is to the Radius. For let A B be a Line inclined to the Plane, and let D E repreſent the Plane. Letting fall from the Points A and B, the Perpendiculars A *a* B *b*, *a b* will be the Projection of the Line A B; to which if we draw thro' B the Parallel Line B C, meeting with the Perpendicular A *a* in C, this Line B C is equal to *a b*: but B C is to A B, as the Sine of the Angle C A B, or the Coſine of the Angle A B C to the Radius, that is, as the Coſine of the Angle of Inclination is to the Radius, ſo is *a b* to A B. Hence it follows, that every Figure, whoſe Plane is Perpendicular to the Plane of the Projection, is Projected in a Right Line. For the Perpendiculars from every Point of the Figure will all fall upon the common Interſection of the Plane of the Figure with the Plane of the Projection. Such a Projection of Lines and Figures is called an *Orthographical* Projection.

An Orthographical Projection what?

IF we imagine a Plane to paſs thro' the Center of the *Earth*, ſo that the Line which joins the Centers of the *Sun* and *Earth*, may be Perpendicular to this Plane, it will make on the Surface of the *Earth* a Circle, which will ſeperate the illuminated Hemiſphere of the *Earth* from the dark. This Circle we before called the Circle bounding Light and darkneſs, but we will now call it the illuminated Disk; which Disk is directly ſeen by a Spectator placed at the diſtance of the *Moon*, in the Right Line which joins the Centers of the *Sun* and *Earth*. Upon this Circle the *Earth*'s Equator, its Parallels, *Poles*, and all the other Circles which we imagined, are to be ſuppoſed Projected *Orthographically*. For all Lines drawn from the Center

The Disk of the Earth.

The Orthographical Projection on the Disk.

Center of the *Sun* to every single Point of the Disk, are to be accounted Parallel; and therefore since that Line which is drawn to the Center of the Disk is perpendicular to it, all the rest will be perpendicular to it; and therefore all Lines drawn from the Center of the *Sun*, and passing thro' every Point of any Circle upon the *Earth*'s Surface, when they are produced will be perpendicular to the Plane of the Disk. Moreover a Spectator in the *Moon* will see all Countries, Cities and Towns, to move upon the Disk, which Motion is occasioned by the Rotation of the *Earth* round its *Axis*, and every Point will have its way on the Disk: for by the Diurnal gyration all places describe either the Æquator, or one of its Parallels; and if the *Sun* be in the Plane of the Æquinoctial, or rather if the Plane of Æquinoctial passes thro' the *Sun*, the Æquinoctial and all its Parallels are in that case projected into Right Lines, for they will all be Perpendicular to the Disk, or the Plane of the Projection. But in other Positions the Projections of these Circles will be Ellipses, which are the ways that all the places of the *Earth* are seen to move in on the Disk: Now if thro' the *Pole* and the *Sun* there be a great Circle drawn which cuts the *Earth*, and this Circle be Projected on the Disk, we shall have an Universal Meridian, to which when any place is observed to come, the Inhabitants of that place will have mid-day. And when any place is first seen to touch the *Western* Limb, or edge of the Disk, the Inhabitants of that place will then see the *Sun* arising upon them. But a Spectator at the *Moon* will see the place to rise and come upon the Disk, and will see it move towards the *East*: And as soon as it has passed the Universal Meridian, the place then being gone to the *Eastward*; the *Sun* seen out of the *Earth* from the place will appear to move *Westward*. But when the place comes to the *Eastern* edge of the

Lecture XIII.

The Universal Meridian.

Lecture XIII.

the Disk, our Spectator in the *Moon* will observe the place to sett in the Disk, and hide itself in the dark side; but the Inhabitants of that place upon the *Earth*'s Surface will see the *Sun* sett in the *West*, and withdraw himself out of Sight.

The bigness of the Disk determined.

THE bigness of the Disk is to be estimated by the Angle under which the *Earth* is seen from the *Moon*, and is of the same quantity with the *Horizontal Parallax* of the *Moon*. And if from the *Moon* there be let fall a Perpendicular upon the Plane of the Ecliptick, which Measures the distance of the *Moon* from the Ecliptick, this Line being Parallel to the Plane of the Disk, will be Projected into a Line equal and Parallel to itsself, and the Angle under which the Projection of this Line appears from the *Moon*, will be equal to the Angle under which the same Line is seen from the *Earth*; for equal Right Lines at equal distances being seen directly, appear under equal Angles.

The Projection of the Moon's way on the Disk.

The way of the *Moon* from the *Sun*, if such a small Portion of it be taken as is turned towards the Disk in the time of an Eclipse, may be esteemed as a Right Line, and will be Projected upon the Disk into a Right Line which is equal to itself, and its Projection with the Projection of the Circle of Latitude will contain the same Angle, that these two Lines make in the Heavens: The Spectator in the *Moon* will see this Line to be described upon the Plane of the Disk, by the Center of the Shadow and of the *Penumbra* which coincide.

Plate X. Fig. 2, 3, 4, 5.

LET now the Circle DGK represent the Disk of the *Earth*, whose Semidiameter let us suppose to be divided into as many parts as the *Horizontal Parallax* of the *Moon* contains Minutes and Seconds. Let the Line NT represent the distance of the *Moon* from the Ecliptick in the time of *New Moon*, Projected on the Plane of the Disk, which also must consist of as many parts as the Latitude of the *Moon*

contains

Lecture XIII.

contains Minutes ; and let likewise K ☊ be a Portion of the Ecliptick, ☊ *l* a Portion of the Way of the *Moon* from the *Sun*, both projected on the Plane of the Disk. From the Center T, let fall on the way of the Shadow a Perpendicular T V ; this Line will measure the least Distance that is between the Centers of the Disk and Shadow.

The Proportion of the Moon's *Latitude.*

At the Center V describe a small Circle, whose Semidiameter may be equal to the Difference of the apparent Semidiameters of the *Moon* and *Sun* ; this Circle will represent the Breadth of the Shadow ; for we have shewed, that this Shadow seen from the *Moon* at the Distance of the *Earth*, was equal to the Excess whereby the apparent Diameter of the *Moon* exceeds that of the *Sun*. Again, let there be described another Circle H M, at the Center V, whose Semidiameter V H bears the same Proportion to the Semidiameter of the Disk, as the Sum of the Semidiameters of both *Sun* and *Moon* bears to the apparent Semidiameter of the *Earth* seen from the *Moon* ; or, which is the same, to the *Horizontal Parallax* of the *Moon* : This Circle will represent the *Penumbra* projected at its shortest Distance from the Center of the Disk ; for we have shewed, that the apparent Semidiameter of the *Penumbra* seen from the *Moon* , was equal to the Semidiameters of both *Sun* and *Moon*.

The Shadow projected.

The Penumbra *projected.*

And therefore if this Circle does not touch the Disk, there can be no *Eclipse* ; that is, if the Distance V T be greater than the Sum of the Semidiameters of the Disk and the *Penumbra*, or, which is the same, greater than the Sum of the Semidiameters of the *Sun* and *Moon* and of the *Horizontal Parallax* of the *Moon*, there can be no *Eclipse*. But if the Distance V T be equal to this Sum, the *Penumbra* will just touch the Disk, without obscuring the *Sun*, or any part thereof : But if V T be less than this Sum, that is, if it be less than VM and TR, the *Penumbra* will cover some part of the Disk ; and those that lie within the Segment R Z M Y, will see at least a partial Eclipse of the *Sun*. But if the Distance V T be less than the Difference of

When there can be no Eclipse of the Earth.

When there must be an Eclipse.

Lecture XIII. the Semidiameter of the Disk and the Semidiameter of the Shadow, then the Shadow will cover ſome part of the Disk, and make a total *Eclipſe* of the *Sun* in all thoſe Places it paſſes over. Theſe total *Eclipſes* are always but for a ſmall portion of Time, becauſe the Diameter of the total Shade is but ſmall; the apparent Diameter of the *Moon* never exceeding the apparent Diameter of the *Sun*, but by a very ſmall matter, which is ſeldom equal to two Minutes; which ſpace the Center of the Shade paſſes over on the Disk in the ſpace of four Minutes of Time; but yet the Stay that it may make on any Place may be longer than this, upon the Account of the Motion of the Place which follows the Shade.

Total Eclipſes of the Sun.

The Ecliptick Limits.

Hence we may know the *Ecliptick Limits*, or the Diſtance of the *Moon* from the *Nodes* at the time of *New Moon*, ſo that an Eclipſe of the *Sun* may be poſſible: for let the Circle R O G repreſent the Disk of the *Earth*, ☊ T K and ☊ N the Projections of a Portion of the Ecliptick, and of the Way of the *Moon* from the *Sun* upon the Plane of the Disk: And let T V be the leaſt Diſtance of the Center of the Disk and Shadow, which ſuppoſe equal to the Sum of the Semidiameters of the Disk and *Penumbra*. Then in the Rectangular Triangle ☊ T V, we have the Side T V; which, when it is biggeſt, is about 94½ Minutes: We have likewiſe the Angle at ☊, which, when it is leaſt, is 5 Degrees and 30 Minutes; from whence we ſhall find ☊ T equal to 986 Minutes, or to 16 Degrees and 26 Minutes. And ſince in this Caſe the *Penumbra* only touches the Disk, it is plain, that there can be no Eclipſe, unleſs the *New-Moon*, be nearer to the *Node* than 16 Degrees and 26 Minutes.

Let the Circle R K G, as before, repreſent the Disk of the *Earth*, ☊ T K a Portion of the Ecliptick projected on the Plane of the Disk, ☊ *l* the Way of the *Moon*'s Shadow on the Disk; T N the Latitude of the *Moon*, and T V the ſhorteſt Diſtance of the Centers of the Shadow and Disk; let

Plate X. Fig. 6.

let the Circle O P Q be the *Penumbra* moving from D by V to *l*; in the middle of which is a small Circle representing the Shadow: And let us suppose we know the Time of the Conjunction, that is, when the Center of the Shadow is in N, which we find by Astronomical Tables; by that means we can find the Time when the Center of the Shade is in V, that is the Time of the middle of the general Eclipse. For in the Rectangled Triangle T V N, we have T N the Latitude of the *Moon*, and the Angle T N V, which the Circle of Latitude makes with the Way of the *Moon* from the *Sun*; and therefore we can find V N and T V. But by the Horary Motion of the *Moon* from the *Sun*, we can find out the Time the Shadow will pass through the space N V; and this Time either added or substracted from the Time of the Conjunction, will give the Time of the middle of the Eclipse. Moreover, in the Triangle D V T, right-angled at V, we have the Side D T, which is the Sum of the Semidiameters of the *Disk* and *Penumbra*, and the Side T V the shortest Distance of the Shade from the Center of the Disk; therefore we can find out the Side D V, and by it the Time when the Shade enters the Disk; and from that we shall have the Semiduration, or half the Time the Eclipse continues upon the Disk. After the same manner we shall find the Time when the Shade leaves the Disk, or the Time of the End of the Eclipse.

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The Time of the middle of the Eclipse.

The Semiduration.

HAVING the Place of the *Sun* in the Ecliptick for any Moment of time, we can thereby find the Place on the Surface of the *Earth*, upon which the *Sun* at that time is Vertical: For the Latitude of the Place is equal to the Declination of the *Sun* at that time; and its Longitude is found by turning the time from the Meridian into Degrees and Minutes of the Equator, allowing for every Hour 15 Degrees, and for every Minute of an Hour 15 Minutes of a Degree. For Example, The Longitude of a Place, in whose *Vertex* the *Sun* is, when at *Oxford* we reckon Nine and an

To find the Place to which the Sun is vertical.

 half

Lecture XIII.

half in the Morning, is known by ſubſtracting 9 and a half from 12, and then there will remain 2 Hours and 30 Minutes, which multiplied by 15 make 37 Degrees and 30 Minutes. And therefore that Place will be 37 Degrees and 30 Minutes to the *Eaſt* of *Oxford*.

LET the Circle F R K repreſent the Disk, as before, F T K a Portion of the Ecliptick projected on the Disk; on which from the Center erect the Perpendicular T R: this Line will be the Projection of the *Axis* of the Ecliptick, and the Point R of its Pole. Let the Point P be the Projection of the Pole of the *Earth*: Through T and the Pole P let us imagine a Circle to paſs, and to be projected on the Disk; this Circle will repreſent the Univerſal Meridian, and the Elevation of the Pole above the Plane of the Disk will always be equal to the Declination of the *Sun*. For the Arch of the Meridian between the *Sun* and the *Periphery* of the Disk, is a Quadrant of a Circle; and the Arch of the Meridian between the Æquator and the Pole is likewiſe a Quadrant: Wherefore taking away from equal Arches the common Arch T P, there will remain P S, the Elevation of the Pole above the Disk, equal to the Diſtance of the *Sun* from the Æquator.

Plate X. Fig. 7.

The Elevation of the Earth's Pole above the Disk.

To find the Poſition of the Meridian, which paſſes thro' the Sun.

IT is here to be obſerved, that when the *Sun* is in the Signs ♑ ♒ ♓ ♈ ♉ ♊, or rather when the *Earth* is in the oppoſite Signs, the Point S, wherein the Univerſal Meridian cuts the Limb of the Disk, will fall towards the Right Hand of the Pole of the Ecliptick. But when the *Sun* is in the other ſix Signs, the Point S falls upon the other Side of the Pole of the Ecliptick, contrary to what happens when the Projection is ſuppoſed to be made in a Plane parallel to the Disk at the Orbit of the *Moon*.

FOR to find the Angle RTS, or the Arch of the Disk intercepted between the Pole of the Ecliptick and the Point S. In the Right-angled ſpherical Triangle R P S, we have the Arch R P, the Diſtance of the Poles of the Ecliptick and Æquator $23\frac{1}{2}$ Degrees;

grees; also the Side P S, which is equal to the Declination of the *Sun*: Wherefore, by *Trigonometry*, we may find the Side R S, or the Measure of the Angle R T S.

Lecture XIII.

To find the Place of the Earth *which is first touched by the* Penumbra.

FOR to find the Place upon the *Earth*'s Surface Q, where the *Sun* rising begins to be in an Eclipse in its upper Limb, and where the Shadow enters the Disk. Draw through the Pole the Meridian P Q, to the Point Q where the *Penumbra* first touches the Disk. And first in the right lined Triangle D T V, having D T and T V, we may know the Angle D T V; to which if we add or substract a given Angle V T P, which is the Sum or Difference of two known Angles V T N and N T P, we shall have the Angle Q T P. And then in the spherical Triangle on the Surface of the *Earth* S P Q, which is Right-angled at S, we have S P equal to the Declination of the *Sun*; and the Arch S Q which is the Measure of the known Angle S T Q; from whence we may find the Arch P Q the Complement of the Latitude of the Place Q, and the Angle S P Q, whose Complement to two Rights is the Angle Q P T, contained between the Meridian of the Place Q and the Meridian of that Place to which the *Sun* is then vertical, and is the Measure of the Distance of the Meridian of the Place Q, from that of the Place which has the *Sun* in the Meridian at that time. But we know the Place which has the *Sun* at that time in its Meridian; wherefore we know likewise the Meridian or Longitude of the Place Q: But its Co-Latitude P Q was before found out. Having therefore both the Longitude and Latitude of that Place, the Place itself must be known.

BY the same Method we can find out the Place of the *Earth*, which is first involved in the total Shadow. And by a like Process we may find out the Place M on the Surface of the *Earth*, which is under the total Shadow at any Point of Time, either before or after the middle of the Eclipse. For the time being known, we may find by the Horary Motion of the *Moon* from the *Sun*, the

Lecture XIII.

Line M V and the Point M, where the Center of the Shadow lies: and in the right-lined Triangle M V T, having M V and V T, we may find M T and the Angle M T V; to which if you add or ſubſtract the known Angle V T P, we ſhall have the Angle M T P. But M T is the Sine of an Arch of the vertical Circle which paſſes through M and the Point of the *Earth*'s Surface directly under the *Sun*, the Semidiameter of the Disk being made the Radius. And therefore if we ſay; As the Semidiameter of the Disk is to M T, So the Radius to the Sign of an Arch: The Arch found out by this Proportion will be the Diſtance of the *Sun* from the *Vertex* M. And therefore in the Spherical Triangle on the Surface of the *Earth* M P T, we have P T the Diſtance of the *Sun* from the Pole, and M T the Diſtance of the *Sun* from the *Vertex*, and the Angle M T P. Hence we can find M P, which is the Complement of the Latitude of the Place, and the Angle M P T, which ſhews the Difference of the Meridians of the Place M, and of that Place to which the *Sun* at that time is vertical; which Place by the time is known: and therefore we can find the Place M. And by this Method we may find ſeveral Places over which the Shade does paſs; and if they be joined by Lines, we ſhall have the Way of the Shade upon the Surface of the *Earth*.

The Determination of the Place involved by the Shadow, for any given Time.

THE Portion of the Diameter of the *Sun* obſcured by the *Moon*, is known by the Situation of the *Spectator* within the *Penumbra*, or by his Diſtance from the Center of the Shade. For let A S B be the Diameter of the *Sun*, parallel to the Diameter of the *Penumbra* E F; draw the Line M C B, touching the ſuperior Edges of both *Sun* and *Moon*; and let F C A alſo touch the inferior Margin of the *Sun*: Then the Angle A C B is equal to the apparent Diameter of the *Sun*; and the Triangles A C B and M C F are ſimilar. Suppoſe then a *Spectator* within the *Penumbra* at G; draw the Line G C P, touching the Globe of the *Moon*, which nearly paſſes through the former

Plate X. Fig. 8.

The Portion of the Solar Disk obscured by the Eclipse.

mer Point C, and cuts off A P, that part of the *Sun*'s Diameter, which is obscured by the *Moon*, to the *Spectator* in G. But the right Line G P, since it very nearly passes through the *Vertex* of the Triangles M C F and A C B, will divide the Bases A B and M F in a like Proportion. And therefore A P is to A B as F G to M F; that is, the obscured Portion of the *Sun*'s Diameter is to the whole Diameter, as the Distance of the Place from the Edge of the *Penumbra*, which is F G, is to F M the Semidiameter of the *Penumbra* diminished by the Semidiameter of the total Shadow.

Lecture XIII.

THE *Astronomers* commonly divide the Diameters of both Solar and Lunar Disks into twelve equal Parts, which they call *Digits*; and by them they measure the Quantity of the Obscuration. And they say, the Eclipse is of so many *Digits*, as the obscured Portion consists of such Parts.

The Quantity of the Eclipse estimated by Digits.

IF we know the Position of any Place upon the Disk for any Point of Time, and it be desired to find the *Phasis* of the Eclipse for that time, as it is seen from the Place; it is to be found in this manner. Let S be the Position of the Place on the Disk; find out for that Point of Time, the Place of the Center of the Shade in its Path; which let it be M. At the Center M, with a Semidiameter equal to the Semidiameter of the *Moon*, describe the Circle A F L: Also at the Center S, with a Semidiameter S B, equal to that of the *Sun*, describe the Circle E F G, which the Circle A F L cuts in E and F; then E B F A will be that part of the *Sun* which is covered by the *Moon* from a *Spectator* in S. For produce the Semidiameter of the *Moon* M A through S, that A D may be equal to the Semidiameter of the *Sun*, which is equal to B S; and then M D will be equal to the Sum of the Semidiameters of both *Sun* and *Moon*; and therefore it will be equal to the Semidiameter of the *Penumbra*: And the Distance of the Place from the Edge of the *Penumbra* is S D: And because B S is equal to A D, A B will be equal to S D. Take A N equal to the Semidiameter of the *Sun*, and

Having the Position of the Place on the Disk, to find the Phasis *of the Eclipse.*

Plate X. Fig. 9.

and then M N will be equal to the Difference of the Semidiameters of the *Sun* and *Moon*, which is equal to the Semidiameter of the total Shadow. But we ſhewed, that S D was to D N, as A B the part of the *Sun*'s Diameter obſcured was to the *Sun*'s Diameter. But A B is equal to S D, and D N is equal to D A and A N, which are equal to two Semidiameters of the *Sun*, or to one Diameter of the *Sun*. Therefore A B is to the Diameter of the *Sun*, as S D the Diſtance of the Place from the Edge of the *Penumbra*, is to D N, which is the Semidiameter of the *Penumbra* diminiſhed by the Semidiameter of the total Shadow. And therefore it is plain, that A B muſt repreſent the Portion of the *Sun*'s Diameter, which is then ſeen to be obſcured.

HENCE alſo is determined the Poſition of the *Cuſpides*, Points or Horns of the Eclipſe; for by drawing the Vertical Circle T S G, the Arches G E, G F, ſhow the Diſtance of the Points from the ſupreme or higheſt Point of the *Sun*'s Limb.

The Velocity of the Shadow on the Disk.

IF the Velocity wherewith the Shadow goes over the Disk, be enquired for, it muſt be obſerved, that the way of the *Moon* from the *Sun* is projected on the Disk in a Line parallel and equal to itſelf; which Line is deſcribed by the Motion of the Shadow: And therefore the Velocity of the Center of the Shade is equal to the Motion of the *Moon* from the *Sun*. Now the Motion of the *Moon* form the *Sun*, is about $30\frac{1}{2}$ Minutes in an Hour; though it is ſometimes more, and ſometimes leſs. And therefore the ſpace, which the Center of the Shade moves through in an Hour, is about $30\frac{1}{2}$ Minutes of the Lunar Orbit. Now the Semidiameter of the Lunar Orbit is about 60 Semidiameters of the *Earth*; and therefore one Minute of the Orbit of the *Moon* is as much as 60 on a great Circle of the *Earth*, or as much as one Degree, that is, 69 *Engliſh* Miles. And therefore $30\frac{1}{2}$ Minutes are equivalent to 2104 *Engliſh* Miles; which ſpace the Shade moves through on the Disk in one Hour. But though

this

Plate X

front. p. 138.

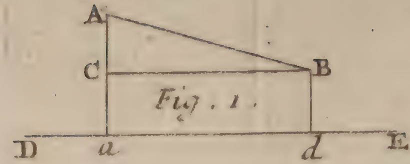

Fig. 1.

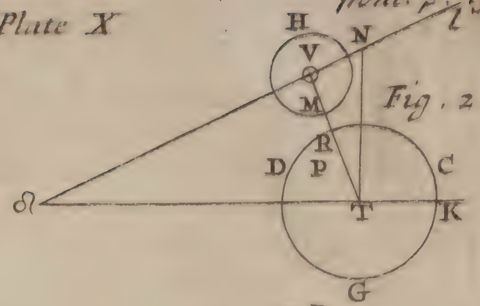

Fig. 2.

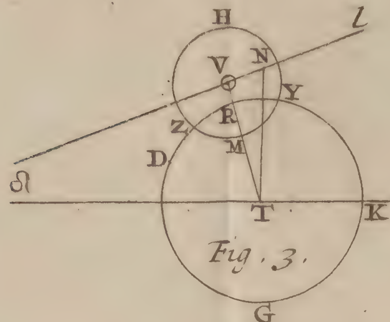

Fig. 3.

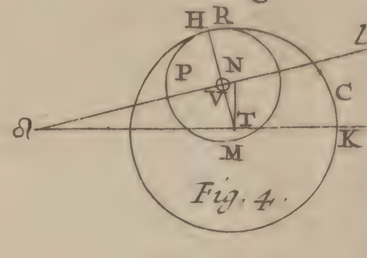

Fig. 4.

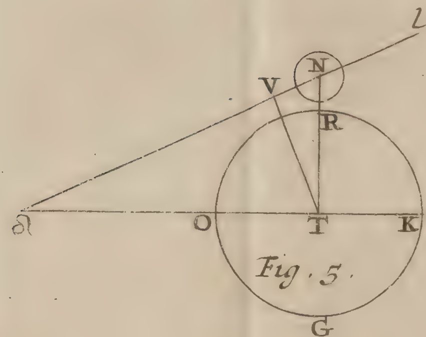

Fig. 5.

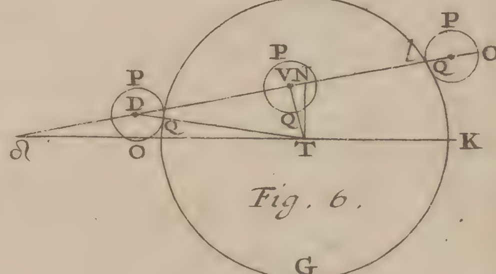

Fig. 6.

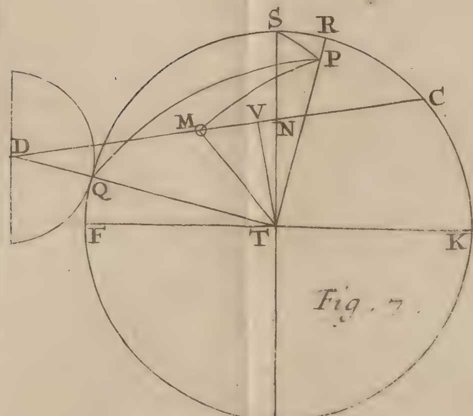

Fig. 7.

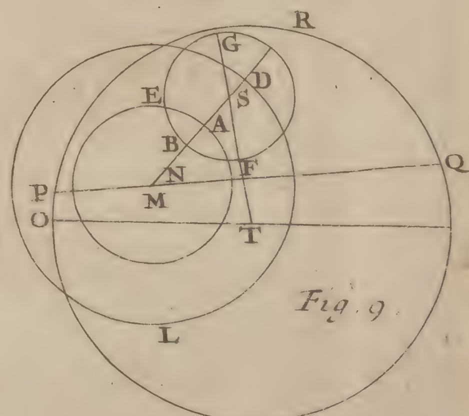

Fig. 9.

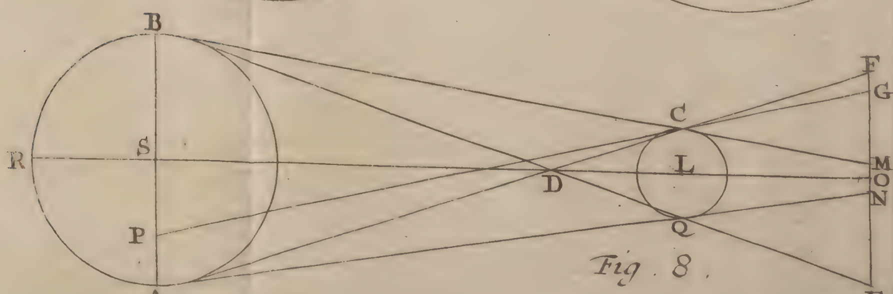

Fig. 8.

this be the Velocity of the Shadow on the Disk, yet the Velocity whereby the Shade recedes from any given Place on the *Earth*'s Surface, is leſs than it; by reaſon that while the Shadow moves from the *Eaſt* to the *Weſt*, all the Places of the *Earth* are likewiſe carried by the Rotation of the *Earth* the ſame way: And therefore following the Motion of the Shadow with a ſlower pace, they diminiſh the Velocity whereby the Shade moves from them.

Lecture XIV.

LECTURE XIV.

A new Method of Computing Eclipſes of the Sun, *as they are to be obſerved from any given Place on the* Earth's *Surface.*

HITHERTO we have explained all the *Phaſes* and Appearances of a General Eclipſe, ſuch as a *Spectator* at the *Moon* would obſerve; and we have ſhewed the Methods whereby the Beginning, Middle, and End of an Univerſal Eclipſe may be determined. But this Beginning and End can be obſerved by only a few, who lie near the Edge of the Disk, where the Shadow enters. In other Places lying towards the middle of the Disk, there will be no Eclipſes ſeen, till ſometime after, when the Margin or Edge of the *Penumbra* comes to touch them. And the End will be when the oppoſite part of the *Penumbra* leaves them. And therefore, according to the different Situation of Places, the Quantity of the viſible Eclipſe will be different, as likewiſe their Beginning, End and Duration.

The Beginning of an Univerſal Eclipſe can be obſerved by very few.

And the Beginnings in particular Places are very different.

THEREFORE to compute the particular *Phaſes* of an Eclipſe, as it is to be obſerved from a certain

Lecture XIV. certain Place, we must here explain a new Method, whereby, without the troublesom and tedious Calculations of *Parallaxes*, which all the *Astronomers* have made use of before, the particular *Phases* may be shown.

A new Method to compute the Phases *for a particular Place.*

Plate XI. Fig. 1.

LET therefore the Semicircle AEB, be half the Disk of the *Earth*, in whose Circumference is the Point E, which answers to the Pole of the Ecliptick. And let the Pole of the *Earth*, or the Æquator, be projected into P. Because all the Places of the *Earth*, being carried by the Diurnal Rotation, describes Circles, which are the Æquator or its Parallels; and all the Parallels, except in the *Æquinoxies*, are inclined to the Plane of the Disk, the Parallel which any Place describes will be projected into an Ellipse, which will be the Way or Path in which that Place will be seen to move by a *Spectator* at the *Moon*. Let therefore FXIID be the Ellipse in which the Parallel of any Place is projected on the Disk: And let the Points in which the Horary Circles cut the Parallels, be likewise projected: And let these Points be VI, VII, VIII, IX, X, XI, XII. I, II, III, IV, V, VI. So at Six in the Morning the Place on the *Earth*'s Surface will be seen on the Disk at VI; at the seventh Hour it will be at VII, at Eight of the Clock it will be at VIII, and at Nine it will be in the Point IX, and so on.

LET CT be a Portion of the Path of the Shadow received on the Plane of the Disk: And suppose the Center of the Shade at Two of the Clock to be in the Point 2; at Three of the Clock let the Place of the Shadow be 3; and at Four let it be in the Point 4, *&c.* At Two of the Clock the Seat of the *Spectator* on the Disk is II; and therefore his Distance from the Center of the Shadow is 2 II: But if we measure this Distance according to the Path of the Shadow, we must let fall from the Place a Perpendicular to the Path, which let be II L, and the Distance thus estimated will be 2 L; and the Point L will be the Position of the Place reduced to the Path of the Shadow.

At

At Three of the Clock the Shadow is at 3, and the Place at III, and their Diſtance is 3 III, which is leſs than the former Diſtance at Two. At the fourth Hour the Shadow is in 4, and the Place in IV. All which time the Shadow advances nearer to the Place, till at laſt the Edge of the *Penumbra* touches it, and then the Eclipſe will begin at that Place. At the fifth Hour, when the Center of the Shadow is at 5 and the Place is in V, it will be there more within the *Penumbra* than it was before, and the Shadow will be near the Place: But at Six the Shadow being at 6 and the Place at VI, the Shadow will have got to the *Eaſt* of the Place, which is then in the Point of the Disk at VI; and therefore the Center of the Shadow has paſſed by the Place, and the time of the ſhorteſt Diſtance between the Center of the Shadow and the Place, will be between the Hours of 5 and 6. After this time the Diſtance of the Shadow and Place will conſtantly grow greater, and at laſt the *Weſtern* Edge of the *Penumbra* will leave the Place, and there will be an End of the Eclipſe upon that Place. But by the following Method the Beginning, Middle, End and Duration of the Eclipſe will be more accurately determined. Upon which account we muſt firſt premiſe the two following Problems.

PROBLEM I.

To find upon the Disk of the Earth *the Poſition of a Place for any given Point of Time.*

LET the Semicircle A E B repreſent half the Disk, A B a Portion of the Ecliptick projected on the Disk, its *Axis* projected S E, meeting with the *Periphery* of the Disk in E, which will be the Pole of the Ecliptick on the *Earth*'s Surface. Let S P be the Line on which the *Axis* of the *Earth* is projected, and P the Projection of the Pole. As the *Radius* is to the *Sine* of the Latitude of the Place, ſo let S P be to S H, and the Point H will be the Projection

Plate XI. Fig. 2.

jection

Lecture XIV. jection of the Center of the Parallel. Through H draw H G equal to the Semidiameter of the Parallel, or to the *Sine* of the Diſtance of the Place from the Pole, which muſt be perpendicular to P S; this will be half the greateſt *Axe* of the Ellipſe into which the Parallel is projected. As the *Radius* is to the *Sine* of the Pole's Elevation above the Plane of the Disk, ſo let G H be to H L, and H L will be the leſſer half *Axis* of the Ellipſe. In G H take H Q, which has the ſame Proportion to G H that the *Sine* of the Angle which the Horary Circle and the Meridian make together, has to the *Radius*; and draw Q R perpendicular to G H: Alſo make the Proportion, As the *Radius* to the Co-ſine of the Angle which the Horary Circle and the Meridian make together, ſo the leſſer *Semiaxe* H L to a fourth, to be laid on the Line Q R from Q to R; and then the Point R will be the Poſition of the place on the Disk required at the Moment of the Time given.

THE ſame may be done by the Help of the Horary Circle.

LET A O B be half the Disk, P the Pole, S P the *Univerſal Meridian*, meeting with the Disk in G; and let F P O be the Horary Circle for the Moment of Time given. In the Right-angled Triangle P G O, we have P G the Elevation of the Pole above the Disk; and the Angle G P O, which the Horary Circle makes with the Meridian. Whence we ſhall find out the Angle G O P, the Inclination of the Horary Circle to the Plane of the Disk, and the Arches P O and G O; and therefore we have the Point O where the Horary Circle cuts the Disk. Draw S O, which will be the common Section of the Horary Circle with the Plane of the Disk: Let P F be the Complement of the Latitude of the place. And S O being the *Radius*, take S Q, equal to the *Sine* of an Arch, whoſe Complement is the Sum of two Arches that are known, *viz.* F P and P O; and let D be the Co-ſine of the ſame Arch whoſe *Sine* is

Plate XI. Fig. 3.

S Q;

SQ. At Q upon OS erect the Perpendicular QR, so that D may have the same Proportion to QR, that the *Radius* has to the *Cosine* of the Inclination of the Horary Circle to the Plane of the Disk, and R will be the Point which was desired, and shews the Position of the place on the Disk for the Time given. Lecture XIV.

The same thing may be likewise found out this way. Calculate (by the *Problems* demonstrated in the *Spherical Doctrine*, and in the *Problems* to be found where the Use of the Globes is taught) for the Moment of Time given, the *Sun*'s Altitude, and the Angle between the Vertical and Hour-Circle at his Center, and make the Angle RSP equal thereto; and take SR equal to the *Sine* of the Complement of the Altitude, or the *Sine* of his Distance from the *Vertex*, SE being the *Radius*, and then R will be the Point required. By the same Methods for all other different Moments of Time, we can find out other Positions of the place on the Disk. The Demonstrations of all these Practices are easily deduced from the Laws of *Orthographical Projection*. Plate XI. Fig. 2.

PROBLEM II.

To find in an Eclipse the Position of the Center of the Shadow on the Disk, for any given Time.

Let AEB, as before, represent the *Semidisk*, SE the *Axis* of the Ecliptick, CT the Path of the Shadow while it passes over the Disk; and let it cut the *Axis* of the Ecliptick in N. Now when the Center of the Shadow is in N, then is the true Conjunction of the *Sun* and *Moon*, whose Time is known by Astronomical Tables. We have likewise by the same Tables the Horary Motion of the *Moon* from the *Sun*. Say, As the Horizontal *Parallax* of the *Moon* is to the Horary Motion of the *Moon* from the *Sun*; so is the Semidiameter of the Disk to a fourth Line M: This will be the space which the Shadow moves through upon the Plate XI. Fig. 4.

Lecture XIV. Disk in an Hour. Then say, As one Hour is to the Time between the Conjunction and the Time for which the Position of the Shadow is sought; so is the Line M to a fourth; this Line will shew the Distance of the Shadow in its proper Path, from the Point of Conjunction N, and consequently the place of the Shadow for the Time given. Suppose the Hour which immediately precedes the Time of Conjunction, to be any Hour you please. For Example, let it be the fourth Hour; Say, As one Hour is to the Time between the fourth Hour and the Time of the Conjunction, so let the Line M be to another, which is N 4; and the Point 4 will be the Position of the Shadow at four of the Clock. Take likewise 4 3, 3 2, 4 5, 5 6, each equal to M; and the Points 2, 3, 4, 5, 6, will shew the place of the Shadow at the Hours 2, 3, 4, 5 and 6.

THESE things being premised, let AEB be half the Disk, as before, CT the Path of the Shadow upon the Plane of the Disk, which the *Axis* of the Ecliptick cuts in N; and when the Shadow comes to N, then is the Time of the true Conjunction. Let, for Example, the 2d be the Hour which immediately precedes the Time of the true Conjunction, and then mark in the Path of the Shadow its places at the Hours 1, 2, 3, 4, 5; and likewise at the same time mark the Situation of the Place on the Disk at the same Hours; let them be I, II, III, IV, V. At one of the Clock the Distance of the Place and Shadow is 1 I; this by applying to a Scale of equal Parts, is to be measured, and taken in Numbers, and from thence deduct the Semidiameter of the *Penumbra* measured by the same Scale, and we have the Distance of the Place from the Edge of the *Penumbra*.

Plate XI. Fig. 4.

The Calculation of the Beginning of the Eclipse.

AT Two of the Clock, after the same manner, take the Distance of the Edge of the *Penumbra* from the Place which is then in II; the Difference of these Distances, since the Edge of the *Penumbra* is in both Cases more *Westerly* than the place, is the

the Appropinquation or relative Motion of the Place to the Shadow in one Hour. Say then, As the Appropinquation of the Margin of the *Penumbra* to the place in one Hour is to the Diſtance of the ſaid Margin from the place at Two of the Clock, ſo one Hour is to the Diſtance of Time from Two till the Beginning of the Eclipſe; which time added to the ſecond Hour, ſhews the time when the Eclipſe begins. Lecture XIV.

The Calculation of the Time of greateſt Obſcuration.

FROM the Poſition of the place at II, to the Path of the Shadow, let fall the Perpendicular II *a*: And becauſe the Center of the Shadow is at 2, the Diſtance of it from the place reduced to the Path, is 2 *a*. Alſo at the third Hour the Poſition of the place being III, let fall from thence a Perpendicular III *b* on the Path; the Diſtance of the Shadow from the place reduced is 3 *b*: the Difference of theſe two Diſtances is the Acceſs of the Shadow to the place reduced, in the time of one Hour. Meaſure this Difference with a Scale, and by the Rule of Proportion ſay, As the Acceſs of the Shadow to the place reduced in one Hour, is to the Diſtance of the Shadow and Place reduced at Three of the Clock; ſo is one Hour, or 60 Minutes, to a fourth Time; which time added to the third Hour, gives the time of the middle of the Eclipſe, or of the greateſt Obſcuration.

The Calculation of the End of the Eclipſe.

AT four of the Clock the Center of the Shadow is in 4, and the place in IV; and becauſe 4 IV is leſs than the Semidiameter of the *Penumbra*, ſubſtract it from the Semidiameter, and there will remain the Diſtance of the place from the Edge of the *Penumbra*. Again, at Five of the Clock the Shadow is in 5 and the place in V; and their Diſtance is 5 V, which is greater than the Semidiameter of the *Penumbra*; and therefore the *Weſtern* Edge of the *Penumbra* is now more advanced towards the *Eaſt* than the Place is; and therefore before that time the *Penumbra* has quitted the Place, and the Eclipſe at an end. From the Diſtance 5 V, ſubduct the Semidiameter of the *Penumbra*, and there will be left the Diſtance be-

Lecture XIV. tween the Place and the *Western* ſide of the *Penumbra*: And becauſe, in the former Caſe at Four of the Clock, the Edge was *Weſtward* of the place, and it has now got to the *Eaſt* of it, the relative Motion of the *Penumbra* and Place muſt be eſtimated by the Sum of theſe two Lines or Diſtances. Say then, As the Sum of theſe two Diſtances is to the Diſtance of the Edge of the *Penumbra* from the place at the fourth Hour; ſo is one Hour to a fourth Time; which Time added to 4 gives the Time when the *Penumbra* leaves the Place, or it will ſhew the End of the Eclipſe.

THE Motion of the Shadow in its Path is equable, at leaſt all the time of an Eclipſe it may be eſteemed equable. But the Motion of a Place upon the Disk is no ways equable, but towards the Edge of the Disk it is ſlower; when it comes towards the middle, it goes through larger ſpaces in equal time. Moreover, our Calculus ſuppoſes, that the relative Motion of the *Moon* and Shadow are equable; and the middle of the Eclipſe, or greateſt Obſcuration, to be where the Line which joins the Place and the Center of the *Penumbra*, is perpendicular to the Path of the Shadow; neither of which is preciſely true, and therefore there will ariſe ſome ſmall Error; but it may be corrected in this manner. At the time of the Beginning of the Eclipſe, find out the place of the Shadow, and likewiſe, for the ſame time, the Situation of the place upon the Disk. At the Center of the Shadow, with a Diſtance equal to the Semidiameter of the *Penumbra*, deſcribe a Circle; if this Circle paſſes through the Point the place is in, then is the Beginning of the Eclipſe rightly determined. But if this Circle does not paſs through the place, note the diſtance of the place and the *Periphery*, and take the relative Motion of the place and Margin of the *Penumbra* for half an Hour; and work again by the Rule of Proportion, as before, and we ſhall then have the true time of the Beginning of the Eclipſe. And by the ſame

Method

Method we may correct the Error, that may arise in computing the End of the Eclipse. And by this means we may have the Beginning and End of Eclipses as accurately as by the common Method, which is by a troublesom Calculation of the *Parallaxes*; where they likewise suppose, that the visible Motion of the *Moon* is equable for a certain time; which, nevertheless, is as unequable as the Motion of a place upon the Disk is.

Lecture XIV.

IF about the time of the middle of the Eclipse, at the Center of the Shadow a Circle be described, whose *Radius* is equal to the Semidiameter of the *Moon*: And if likewise we describe another Circle, whose Center is the place of the *Spectator*, and whose *Radius* is the Semidiameter of the *Sun*; the Intersections of these two Circles will shew the *Phasis* at the greatest Obscuration.

The same may be performed by Trigonometry.

IF there be some who are not pleased with this mechanical way of measuring Lines and Distances by a Scale, they may compute all the Lines by *Trigonometry*, in the following manner. As before let A E B be the Disk of the *Earth*, P the Projection of the *Pole*, C N T the way of the Shadow, the Point 2 its Position at Two of the Clock; and, for the same time, let II be the Situation of the place of the *Spectator*. Let S E be the *Axis* of the Ecliptick, which cuts the Path of the Shadow in N; S N will be the Latitude of the *Moon* at the time of the *Conjunction*. From the Center of the Shadow and the Place draw the Lines 2 S, II S, to the Center of the Disk, and join 2 II: Then in the Right-lined Triangle 2 N S we have N S the Latitude of the *Moon*, and 2 N its distance from *Conjunction* at Two of the Clock. We have likewise the Angle 2 N S, which is the Inclination of the Path to the Circle of Latitude: Wherefore we can find out 2 S and the Angle 2 S N. Again, in the spherical Triangle P S II, we have the side P S the Complement of the *Sun*'s Declination, and P II the Complement of the Latitude, together with the Angle S P II, which is known by the Time; by which we can find the

Plate XI. Fig. 5.

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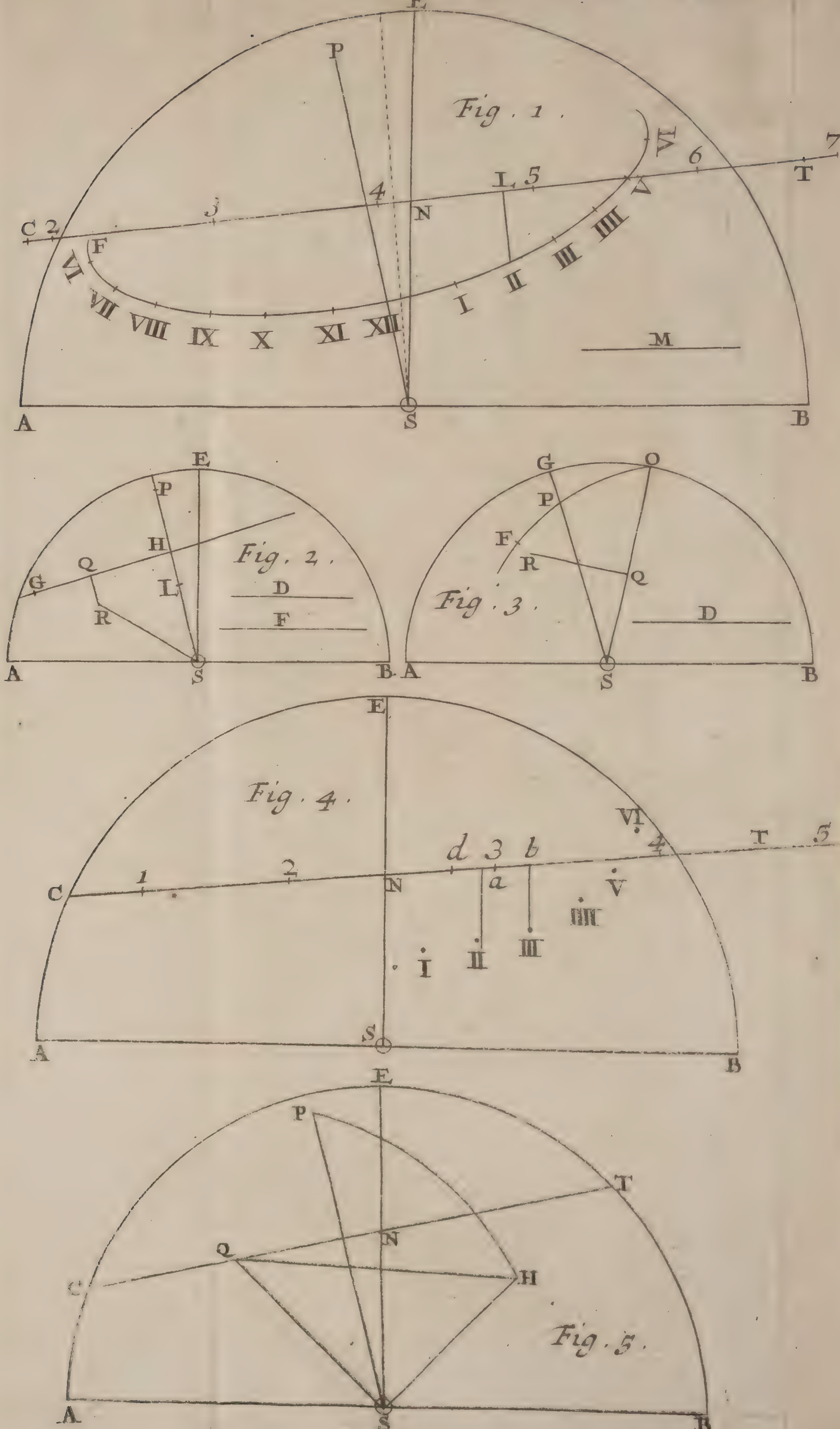
Arch S II, which is the diftance of the *Sun* from the *Vertex*; and the *Sine* of this Arch is juft equal to the diftance S II, S E being made the *Radius*: we may alfo find the Angle P S II; to which if we add, or take away the known Angle P S E, we fhall have the Angle N S II. But the Angle P N S was found out before; wherefore we have the whole Angle 2 S II. Laftly, In the Right-lined Triangle 2 S II we have the two fides 2 S and II S, and the Angle contained between the two fides; and therefore by plain Trigonometry we may find the fide 2 II, which was to be found out. Proceeding by this Method, there is no need for inquiring into the Pofitions of Place and Shadow on the Disk; for they are to be found out by a *Calculus* without Protraction.

To find the Longitude of Places by Obfervations of Solar Eclipfes.

THE Longitudes of places on the Surface of the *Earth* may be found out by Obfervations of Eclipfes of the *Sun*, as well as by thofe of the *Moon*, *viz.* if we obferve in that place whofe Longitude is wanted, the Moment of time when the Eclipfe begins or ends: Let that, for Example, be at Five of the Clock; and at the Center V, with a Diftance equal to the Semidiameter of the *Penumbra*, defcribe an Arch of a Circle cutting the Path of the Shadow in *d*, that Point *d* will fhew the place of the Center of the Shadow at that time. Meafure the Diftance N *d* with a Scale, which being given, together with the Motion of the *Moon* from the *Sun*, we fhall find the time, in the place of the Obfervation, when the true *Conjunction* is celebrated. In like manner, by an Obfervation in any other place we may find when the fame *Conjunction* is celebrated according to the time computed from the Meridian of that place; and the Difference of thofe times being turned into Degrees and Minutes of the Equator, will fhew the Difference of Longitude between thofe two places.

IN Practice it is convenient to make the Semidiameter of the Disk ten Inches, that it may be divided by a Scale into a 1000 parts, which is done

Plate XI fronting p. 148



done by the Help of a Diagonal Scale; for this Number is the *Tabular Radius*: And let SN the Latitude of the *Moon*, and all the Lines whose Dimensions are necessary to be known, be expressed by the same parts. For if we say, as the Horizontal *Parallax* of the *Moon*, which is expressed in Astronomical Tables in Minutes and Seconds, is to the *Moon*'s Latitude, so is 1000 to a fourth Number. And then we take the Line SN out of the Scale, whose Dimension is expressed by this fourth, this Line will represent the Latitude of the *Moon*. And in like manner we are to operate for to find out the length of the way the Shadow advances in an Hour in its Path. And now we have shewed a new way by which the Times and *Phases* of an Eclipse are to be defined, as they are to be seen from a particular place, which does not require a frequent or repeated Calculation of the *Parallax*, for to have the visible place of the *Moon* in the Heavens, both as to Longitude and Latitude; which Method is received by most *Astronomers*. But our Method is much easier, and, as I think, no less accurate. For in the common Method the different Positions of the Ecliptick in respect of the Horizon, which are always changing, will produce great Inequalities in the *Moon*'s Motion, and will make her constantly alter her place, both as to Longitude and Latitude: So likewise as the *Moon* ascends or descends, the *Parallaxes* will always be changeable; and except we often compute them, it will be hard to escape falling into an Error.

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BUT because the Method of computing Eclipses by *Parallaxes* is that which is generally made use of by the *Astronomers*, it will be convenient likewise to explain that Method. And here I suppose the Reader to be already instructed in the Doctrine of the *Parallaxes*, either by other Astronomical Books, where it is explained at length; or by what we shall after this say upon that Subject: And that being understood, the Principles on which the Calculation is founded are easily appre-

 hended,

Lecture XIV. hended, though the Practice of the Rules is very difficult and tedious.

The common Method of computing Eclipses of the Sun.

FIRST of all the visible *Conjunction*, and the Way the *Moon* is then to take in the Heavens, are to be determined. For in this case the true and visible *Conjunction* are very different both as to their Times and Places. The true place of the *Moon* is that which is seen from the Center of the *Earth*, the visible Place is that which is seen from our Habitation on its Surface. Let the Semicircle A B C represent an Hemisphere of the Globe of the *Earth*, whose Center is T; from whence draw the Right Line T L S through the *Moon* at L, and the *Sun* at S at a much greater Distance; and therefore since the Centers of the *Sun* and *Moon* are seen in the same Right Line from the Center of the *Earth*, they will appear in the same Point of the Heavens, and they will be in true *Conjunction*. But a *Spectator*, on the Surface of the *Earth* at A, will observe the Centers of the *Sun* and *Moon* in distinct Points of the Heavens, their Distance being the Arch S E. The Point where the Right Line T L drawn through the Centers of the *Earth* and *Moon* meets with the Heavens, is called the true Place of the *Moon*. But where a Right Line passing through the Eye of the *Spectator* on the Surface and the Center of the *Moon* meets with the Heavens, that Point is called the visible or apparent place of the *Moon*. Let these Points be S and E; the Arch S E, which is the Distance between the true and apparent place, is called the *Moon*'s *Parallax*. Now because the Points T and L, in respect of the immense Distance of the *fix'd Stars*, coincide, the Arch S E will be the same, whether its Center be conceived to be in L, or in T; and therefore the Arch S E is the Measure of the Angle S L E, or of the Angle A L T, which is equal to it. But the Angle A L T is the Angle under which the Semidiameter of the *Earth* A T, drawn thro' the place of the *Spectator*, is seen from the *Moon*: And therefore the *Parallax* of the *Moon* is always equal to this Angle. And this Angle is biggest

Plate XII. Fig. 1.

The Moon's *true Place.*

The Moon's *visible Place.*

The Moon's Parallax.

biggeſt, when the Semidiameter is directly ſeen from the *Moon*; for then the Angle LAT is a Right Angle, and the *Moon* is ſeen in the Horizon, and therefore the *Horizontal Parallax* is greateſt of all. But if the *Moon* ſhould be in the *Vertex* F, the Angle ALT would there vaniſh; and the *Moon*'s true place would coincide with its apparent place, whence there would be no *Parallax*.

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SINCE the *Parallax* of any celeſtial Body is always equal to the Angle under which the Semidiameter of the *Earth*, paſſing through the place of the *Spectator*, is ſeen from that Body, there will be no ſenſible *Parallax* of the *Sun*. For as I have frequently ſaid, the *Earth* ſeen from the *Sun* appears no bigger than a Point, and under no ſenſible Angle: But the *Moon* when it is in the Horizon has a ſenſible *Parallax*, and ſometimes it is greater than a Degree.

The Sun *has no* Parallax.

HENCE it follows, that the *Parallax* always ſhews the *Moon* more depreſſed, or at greater Diſtance from our *Vertex* than it really is: This Depreſſion will change its place according to the Ecliptick, and make the *Moon* appear to have a Longitude and Latitude different from what it has when ſeen from the Center of the *Earth*. For in the Figure, let the Circle HCZ be the Meridian, or the Circle paſſing through the *Vertex* of the *Spectator* and the *Pole*; let Z be the *Vertex*, HED the *Horizon* of the place, CE the Ecliptick, in which let the *Moon* according to its true place be in L, without any Latitude; let ZT be a Vertical Circle paſſing through the *Moon*; and becauſe the *Parallax* always depreſſes the *Moon* in the Vertical, the apparent place of the *Moon* will be further diſtant from the *Vertex* Z than the true place is. Let the apparent place be O, and ſince the true place is L, the *Parallax* will be LO; which being in the Vertical or Circle of Altitude, is called the *Parallax* of Altitude. Through O let there a Circle paſs which is perpendicular to the Ecliptick, meeting with the Ecliptick in *m*, that Point will be the apparent place reduced to the

Plate XII. Fig. 2.

Lecture XIV. Ecliptick, and the Arch L *m* is called the *Parallax of Longitude*, and O *m* the visible Distance of the *Moon* from the Ecliptick, is called the *Moon's Parallax of Latitude*. For determining the *Phases* of Eclipses, as they are to be seen from a given place, it is necessary to know at that time the true places of the *Moon* and *Sun*, which may be computed by Astronomical Tables for any given Moment of Time. Moreover, we must know the apparent place of the *Moon*, which is to be determined from the true place, by a Computation of the *Moon*'s *Parallax*; which being premised, the Times and *Phases* are thus found out.

Plate XII. Fig. 3.

A Calculation of the visible Eclipse.

LET *p k* be a Portion of the Ecliptick, S the place of the *Sun* therein, at the time of the true *Conjunction*; and *l* the apparent place of the *Moon* reduced to the Ecliptick; *l o* the visible Latitude of the *Moon*, and *l* S will be its visible Longitude from the *Sun*. At a small portion of time before the true *Conjunction*, find out again the visible place of the *Moon* in the Ecliptick, which let it be at *p*, and let *p q* be the *Moon*'s visible Latitude: Draw *q o* which produce, and let it meet with the Ecliptick in *k*, and *q k* will be the visible way of the *Moon* from the *Sun* at the time of the *Conjunction*. In the Triangle *q o n*, Right-angled at *n*, we have *o n* the difference of Longitude of the *Moon* from the *Sun* in *p* and *l*, and *q n* the difference of Latitude, whereby we can find the Angle *q o n*, or *q k p*, which is equal to it, and which is the Inclination of the visible way of the *Moon* to the Ecliptick: from thence also we can find the side *q o*, and by them we can find the Lines *o t*, *t k*, S *k*, and S *t*. For *p l* is to *q o*, as *l s* is to *o t*: And in the Triangle *o l k*, by having *o l* and the Angle *k*, we can find *o k* and *l k*, and thereby *l k*, S *k*, and S *t*. Now when the Center of the *Moon* is seen at *t*, then is the visible *Conjunction* of the *Sun* and *Moon*. And therefore we say, As *q o* is to *o t*, or as *p l* is to *l* S, so is the Time that the *Moon* moves through the space *q o*, to the Time it moves through *o t*; and then we shall have the time

time between the true and visible *Conjunction*. From S upon the way of the *Moon* let fall a Perpendicular S *m*, and in the Right-angled Triangle S *k m*, we have S *k* and the Angle *k*; therefore we can find out S *m*, which is the least visible distance, or the nearest Approach of both *Sun* and *Moon*. If this distance be greater than the Sum of the Semidiameters of the *Sun* and *Moon*, there will be no Eclipse visible in that place; but if it be less, the difference reduced into Digits will shew the Quantity of the Eclipse. Having the side S *m*, and the Angle *t* S *m*, which is equal to the Angle *k*, we can find out the Line *t m*, and thence the time the *Moon*, in her visible way, takes to describe the Line *t m*, which is the time between the visible *Conjunction* and the Moment of greatest Obscuration. Lecture XIV.

THE Beginning of the Eclipse is thus determined: Let *p k* be a Portion of the Ecliptick, as before; S the Center of the *Sun*; let *q k* be the visible way of the *Moon*, S *m* its shortest distance from the *Sun*. Draw from the *Sun* to the way of the *Moon* the Right Line *s q* equal to the Semidiameters of both *Sun* and *Moon*: And then when the Center of the *Moon* comes to *q*, the Eclipse will begin to be visible, and the two Margins of the *Sun* and *Moon* will seem to touch one another. In the Rectangled Triangle *q* S *m*, we have the side S *q*, equal to the Sum of the Semidiameters of the *Sun* and *Moon*, and S *m* the nearest Approach of their Centers; from whence we can find out the Angle *q* S *m* the Angle of Incidence, and also the side *q m*; and thereby we have the time wherein the *Moon* describes the Line *q m*, and from thence the time between the Beginning of the Eclipse and the time of the greatest Obscuration.

Plate XII. Fig. 4.

A Calculation of the Beginning and End of the Eclipse.

AFTER the same Method we may find the time of the visible End of the Eclipse. But here we must begin again, and compute a-new by the *Parallaxes* the visible way of the *Moon* from the *Sun*, after the *Conjunction*, which will not be the same it was before. For the Inclination of the

Lecture XIV.

visible way is constantly changing, because the Quantity of the *Parallax* is in a perpetual Flux, as the *Moon* rises and falls in Altitude. Seek therefore, about an Hour after the *Conjunction*, the visible Longitude of the *Moon* from the *Sun*, and its visible Latitude, and from them compute the Inclination of the *Moon's* way from the *Sun*; which being found, by the same Method we found the time of the Beginning of the Eclipse, we may likewise find the time of its End.

A Determination of the Phasis *for any Moment of Time.*

IF the *Phasis* of an Eclipse for any Moment of time be required, find for that time the place of the *Moon* in her visible way, and at that Center, and with a distance equal to the Semidiameter of the *Moon*, describe a Circle; likewise at the Center S, with a distance equal to the Semidiameter of the *Sun*, describe another Circle; the Intersections of these two Circles will shew the *Phasis* of the Eclipse, and the Quantity of Obscuration, as also the Position of the Cusps or Horns.

BEFORE we make an end of this Doctrine of Eclipses, it will be requisite to explain one notable Appearance, and to shew the Reason of it.

IN Total Eclipses of the *Moon*, even when she is near the Center of the Shadow, her Body is frequently to be seen of a pale and languid Colour, which could not be without her being illuminated with some Light; and some will wonder from whence arises this Light. Some suspected that it was the native and proper Light of the *Moon* her self. Others derived it from the *Planets* and *Stars*; for the Interposition of the *Earth* intercepts all the Light of the *Sun*, and seems to bring a thick Darkness upon the whole space taken up by the Conical Shadow. But we must consider that the *Earth* is surrounded with a Sphere of Air of a considerable Depth and Density, which has a refractive Power, whereby it turns the Rays of the *Sun* out of their way when they fall upon it, and makes them enter the Conical Shadow; which therefore will be illuminated by that small Quantity

tity of Light which falls obliquely on our Atmosphere, and imparts to all the Bodies within it a faint Light, the which will illuminate the *Moon*, even when it is in the midst of the Shadow, and make it visible to our Eyes, as the Figure shews.

Lecture XV.

Plate XII. Fig. 5.

LECTURE XV.

Of the Phænomena *or Appearances arising from the Motions of the* Earth, *and the two inferiour Planets* Venus *and* Mercury.

HITHERTO we have contemplated the Motions of the *Earth* and *Moon*, and have given an Account of many Appearances that arise from them. The *Moon* indeed is no primary *Planet*, but a secondary, which does no other ways go round the *Sun* the true Center of our System, than by accompanying our *Earth* to whom she properly belongs, in her annual Course round the *Sun*.

The six Primary Planets.

BUT the Chief and Primary *Planets* of our System, which perform their Circulations round the *Sun*, without regarding any other Body, are in Number six, *viz. Mercury* ☿, *Venus* ♀, the *Earth* ⊕, *Mars* ♂, *Jupiter* ♃, and *Saturn* ♄, whose Motions and Appearances are now to be explained. And, *first*, we have already demonstrated, that the Orbits of *Venus* and *Mercury* include the *Sun*, and that they are included within the Orbit of the *Earth*; and since they finish their Circulations in less time than the *Earth* does, it is manifest that these *Planets* seen from the *Sun*, will

appear

Lecture XV. appear in the Heavens ſometimes nearer, and ſometimes further from the *Earth*; and that ſometimes they may from thence appear in the ſame Point, and ſometimes in oppoſite Points of the Heavens, with the *Earth*. And becauſe *Venus* and *Mercury* are carried faſter about than the *Earth*, a *Spectator* in the *Sun*, after ſeeing either of them in *Conjunction* with the *Earth*, will ſee it recede from the *Earth*, which follows with a ſlower Motion, and get by degrees a good way to the *Eaſt* of the *Sun*.

AS theſe *Planets*, ſeen from the *Sun*, change their Poſitions in reſpect to the *Earth*, ſo likewiſe we ſeeing them from the *Earth*, obſerve that they change their Poſitions in reſpect to the *Sun*, and are ſometimes nearer, ſometimes further removed from him; and ſometimes they appear in *Conjunction* with the *Sun*. But the *Conjunctions* of theſe *Planets* ſeen from the *Earth*, do not only happen when the *Earth* and they are ſeen together in *Conjunction* from the *Sun*, but alſo when a *Spectator* in the *Sun* ſees the *Earth* and them in Oppoſition: even then the *Sun* and they ſeen from the *Earth*, appear to be in *Conjunction*. For let S be the *Sun*, A B C the Orbit of the *Earth*, F H V the Orbit of *Venus*; and let the *Earth* be in T and *Venus* in V, in the Line which joins the Centers of the *Earth* and *Sun*: In this Poſition *Venus* ſeen out of the *Sun* is in *Conjunction* with the *Earth*, as the *Sun* from the *Earth* is ſeen conjoined with *Venus*.

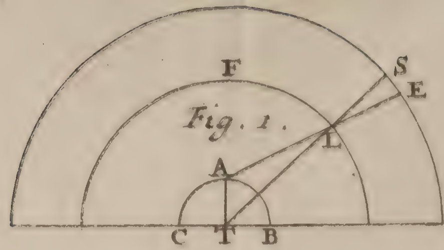
Two Caſes of Conjunctions.

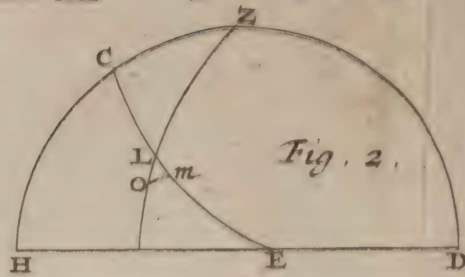
Plate XIII. Fig. 1.

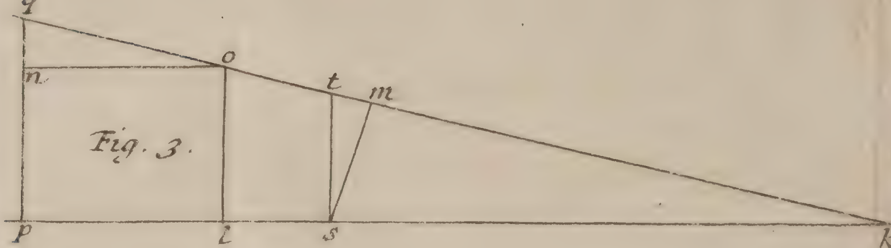
BUT if the *Earth* were in T, and *Venus* in F, a *Spectator* in the *Sun* will ſee *Venus* and the *Earth* in Oppoſition, or in oppoſite Points of the Heavens. But a *Spectator* in the *Earth* will ſee *Venus* not in Oppoſition to the *Sun*, but in *Conjunction* with him. In the firſt Caſe of theſe *Conjunctions* *Venus* is between the *Sun* and the *Earth*; in the other the *Sun* is ſituated between the *Earth* and *Venus*; and *Venus* goes above the *Sun*: the firſt is called the *inferiour Conjunction*, the ſecond the *ſuperiour*.

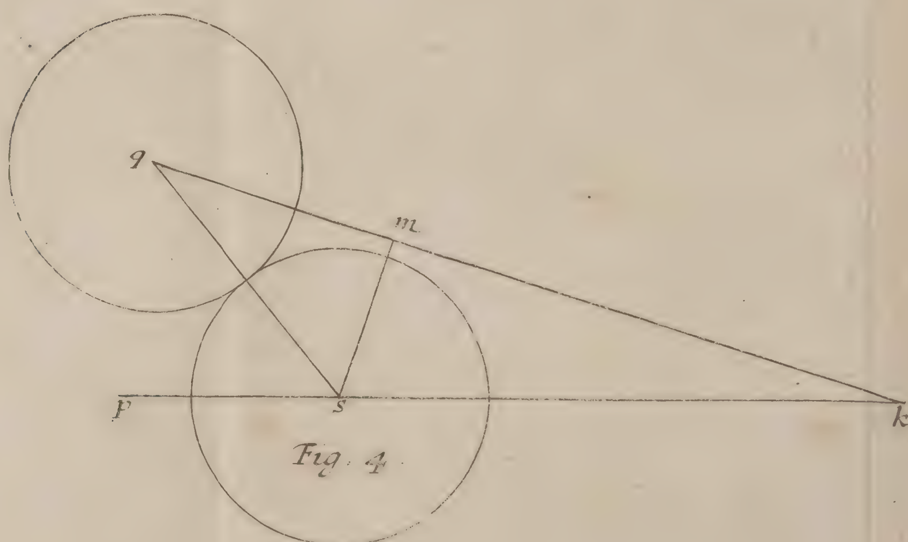
AFTER

Plate XII *fronting . p . 155.*









AFTER either of these two sorts of *Conjunctions*, *Venus* will seem daily to remove further from the Neighbourhood of the *Sun*, and will daily seem to get further off from him; but still she keeps within certain Bounds, for she never comes to be opposite to the *Sun*; nor does she even arrive at *Quadrantile Aspect*, which is 90 Degrees, or a *Sextile Aspect*, which is 60 Degrees distant from the *Sun*. And *Venus* is seen at her greatest distance from the *Sun*, when the Line which joins her Center with the *Earth* touches the Orb of *Venus*, as about D. For when this *Planet* is further advanced to H, its place in the Heavens is seen to be nearer to the *Sun* than it was before at D. Now before she came to D, she always receded more and more from the *Sun*. And after she has left D, she every Day comes nearer to the *Sun*: It is necessary, that between the times of her Recess and Approach, she become stationary in respect to the *Sun*, and for some time appear to keep the same distance from him; at which time the visible Motion of *Venus* will be equal to that of the *Sun*. The Arch of a great Circle intercepted between *Venus* and the *Sun*, is called the *Elongation* of that *Planet* from the *Sun*.

The Elongation of a Planet *from the* Sun.

BUT here it is to be observed, that only in a Circle, which has the *Sun* for its Center, the greatest Elongation happens, when the Right Line which joins the *Earth* and *Planet* touches. For in an Elliptick Orbit it may be, that the Elongation from the *Sun* may grow still greater, even after it has left the place where the Line joining the *Earth* and *Planet* touches its Orbit. For after that, the true distance of the *Planet* from the *Sun* may increase, whilst the distance of the *Sun* and *Planet* from the *Earth* does not increase, but they may rather decrease. And therefore in two Triangles the greater Base will subtend the greater Angle. But because the Orbits of the *Planets* are nearly circular, such small differences may be here neglected.

The Elongation is not always greatest when it is in a Line touching the Planets *Orbit.*

THE

Lecture XV.

THE greateſt Elongation of *Venus* is found by Obſervation to be about 48 Degrees, by which in a circular Orbit we may know the diſtance of *Venus* from the *Sun* in reſpect of the *Earth*'s diſtance from the ſame: For S T is to S D, as the *Radius* is to the *Sine* of the Angle S T D, which is the greateſt Elongation.

HENCE alſo it is manifeſt, that *Venus*, from the time of her ſuperiour *Conjunction*, where ſhe is furtheſt from the *Earth*, to the time of her inferiour *Conjunction* with the *Sun*, where ſhe approaches neareſt it, is always ſeen more *Earſterly* than the *Sun*; and all that time *Venus* ſets later than the *Sun*, and is ſeen after Sun-ſetting; and then ſhe is called the *Evening-Star* or *Veſperus*, being a Fore-runner of Night and Darkneſs. But from the inferiour *Conjunction*, till ſhe comes again to the ſuperiour, ſhe is always obſerved to be to the *Weſtward* of the *Sun*, and conſequently muſt ſet before him in the Evening, and riſe before him in the Morning, and then ſhe is only to be ſeen before Sun-riſing; when ſhe is called the *Morning-Star* or *Phoſphorus*, her Appearance foretelling that Light and Day are at hand.

LET us now ſuppoſe *Venus* and the *Earth* to be ſeen out of the *Sun* in *Conjunction*, and the one to be at V, the other in T, in the ſame Point of the Ecliptick: In which Poſition *Venus* and the *Sun* are ſeen from the *Earth* likewiſe in *Conjunction*. After this, *Venus* circulating faſter than the *Earth*, being come again to V, and having finiſhed her Courſe, and by an angular Motion round the *Sun* deſcribed four Right-angles, will not have overtaken the *Earth*; who in the mean time has proceeded further in her proper Orbit. And therefore *Venus* muſt ſtill move further on to come in a Right Line between the *Sun* and the *Earth*. Let S L M be the next Right Line in which *Venus* is ſeen from the *Sun* together with the *Earth*, ſo that *Venus* may be in L when the *Earth* is in M: now before *Venus* can overtake the *Earth*, ſhe muſt not only finiſh her whole Circula-

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tion or four Right-angles, but alſo ſo much angular Motion more as the *Earth* has made in the mean time round the *Sun*. Now the angular Motions of *Venus* and the *Earth* performed in the ſame time, are reciprocally as the Periodical Times of *Venus* and the *Earth*. And therefore as the Periodical Time of the *Earth* is to the Periodical Time of *Venus*, ſo is the angular Motion of *Venus* (which is equal to four Right Angles, and moreover to the angular Motion the *Earth* makes from the time of one *Conjunction* to the next) to the angular Motion of the *Earth*. And therefore by Diviſion of Proportion, As the Difference between the Periodical Times of the *Earth* and *Venus* is to the Periodical Time of *Venus*, ſo are four Right Angles to a fourth Quantity; which ſhews the angular Motion of the *Earth* from the time of her *Conjunction* with *Venus*, to the time of the next *Conjunction* of the ſame kind. Now the Periodical Time of the *Earth* is 365 Days and 6 Hours, or 8766 Hours. And the Period of *Venus* conſiſts of 224 Days 16 Hours, or 5392 Hours, whoſe Difference is 3374 Hours. Say then, As 3374 is to 5392, ſo are four Right Angles or 360 Degrees, to a fourth Number of Degrees, which is 575; which Motion is equal to a Circulation and a half, and beſides to 35 Degrees; which angular Motion the *Earth* makes in the ſpace of one Year and 218 Days. And therefore if *Venus* ſhould be this Day in *Conjunction* with the *Sun* in the inferiour part of her Orbit, ſhe will not come to the ſame *Conjunction* again till after a Year and ſeven Months and twelve Days. And if one *Conjunction* be in the beginning of *Aries*, the next will fall out when the *Sun* is in *Scorpio*. There is the ſame diſtance of time between any two other ſimilar Poſitions of *Venus* and the *Sun*. For Example, between two ſuperiour *Conjunctions*, or between two ſuch Situations of *Venus*, where ſhe has a given Elongation from the *Sun* the ſame way.

The time between two Conjunctions *of the ſame kind.*

THIS

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THIS *Problem* and another of the ſame Nature about the *Conjunctions* of the *Sun* and *Moon*, are otherwiſe ſolved by the *Aſtronomers*; for they find out the Diurnal Motion of *Venus* ſeen from the *Sun*, and likewiſe the Diurnal angular Motion of the *Earth*; and the difference of theſe Motions is the relative Diurnal Motion of *Venus* from the *Earth*, or the Quantity by which *Venus* is ſeen to recede from the *Earth* every Day by a *Spectator* in the *Sun*. Thus the middle Motion of the *Earth* is every Day about 59 Minutes and 8 Seconds: *Venus*'s middle Motion in a Day, is 1 Degree 36 Minutes and 8 Seconds, whoſe difference is 37 Minutes. Say therefore, As 37 Minutes is to 360 Degrees, or to 21600 Minutes, ſo is one Day to that ſpace of time, wherein *Venus* having left the *Earth*, has receded from her 360 Degrees; that is, to the time in which ſhe returns to the *Earth* again, which is the time between two *Conjunctions* of the ſame kind, which will be found to conſiſt of 583 Days.

Another way of doing the ſame.

BUT theſe *Conjunctions* are here computed according to the middle Motions of the *Planets*, ſuppoſing them to move always equably, or with the ſame angular Velocity; and they are therefore called *mean Conjunctions*. But becauſe *Venus* and the *Earth* are really carried in Elliptick Orbits, in which their Motions are conſtantly variable, ſometimes going faſter, and ſometimes ſlower; it may be, that the true *Conjunctions* ſhall happen ſome few Days ſooner or later than the Computation we have given; yet having the time of the *Mean Conjunction*, the true *Conjunction* is from thence to be computed after this manner: Let ABC be the Ecliptick, in which A is the Point where the *Planets* are to be in *Conjunction* according to the mean Motion. For the time of this *Conjunction* compute by Aſtronomical Tables the true Places of the *Earth* and *Venus* in the Ecliptick; and ſuppoſe *Venus*'s true place in the Ecliptick to be D, and the *Earth* in T, by which we ſhall find the diſtance of the *Earth* and *Venus*

Plate XIII. Fig. 2.

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ſeen from the *Sun*: But we have, for that time, the Angular Motions of theſe two *Planets* for any given ſpace of time; for Example, for ſix Hours; and the difference of theſe two Motions will give the Acceſs of *Venus* to the *Earth*, or her Receſs from it in ſix Hours. Say then, As this difference of Motions is to D T, ſo is ſix Hours to the time between the Mean *Conjunction* and the true; which time added to, or ſubſtracted from the time of Mean *Conjunction*, as *Venus* is to the *Eaſt* or *Weſt* of the *Earth*, ſhews the time of their true *Conjunction*.

Venus conſtantly changes her diſtance from the Earth.

IT is plain from the Inſpection of the Figure, that though *Venus* does nearly always keep the ſame diſtance from the *Sun*, yet ſhe is continually changing her diſtance from the *Earth*; and her diſtance is greateſt, when ſhe is ſeen in her ſuperiour *Conjunction* with the *Sun*; and it is the leaſt when ſhe is in her inferiour *Conjunction*: And the difference is ſo great, that it equals the whole Diameter of *Venus*'s Orbit; ſo that the diſtance of *Venus* from the *Earth*, when ſhe is in her ſuperiour *Conjunction*, is to her diſtance from the *Earth* in the inferiour, as 1 to 6: And therefore *Venus* approaches the *Earth* ſix times nearer in the one Poſition than in the other; and juſt ſo much are the apparent Diameters of *Venus* changed, as we obſerve them to be. But theſe greateſt and leaſt diſtances are ſomewhat changeable upon the Account of the Elliptical or Excentrick Orbits: For *Venus* is then moſt remote from the *Earth*, where the ſuperiour *Conjunction* happens when *Venus* and the *Earth* are both in their *Aphelions*. And the diſtance of *Venus* and the *Earth* is the leaſt of all, when the inferiour *Conjunction* falls out when *Venus* is in her *Aphelion* and the *Earth* in her *Perihelion*.

The Phaſes *of* Venus *like thoſe of the* Moon.

BECAUSE *Venus* is an opake Globe without any Light of her own, and only ſhines with the borrowed Light of the *Sun*, that Face of *Venus* will only appear bright, which is turned towards

Lecture XV. wards the *Sun*, while the oppoſite remains in Darkneſs; and for want of Light, is altogether inviſible. Wherefore if the Situation of the *Earth* be ſuch, that this dark ſide of *Venus* be turned toward the *Earth*, *Venus* will become inviſible, except by chance ſhe appear like a black Spot in the Disk of the *Sun*: But if the whole illuminated Face of *Venus* be turned towards the *Earth*, as it is when ſhe is near her ſuperiour *Conjunction*, then ſhe appears like a full ſhining Orb: and according to the different Poſitions of the *Earth*, *Venus* and the *Sun*; *Venus* will have different Forms, and appear with different Faces and Figures, and will undergo the ſame Changes and Viciſſitudes in her Appearances that the *Moon* does.

Plate XIII. Fig. 3. LET A B C D E F G H be the Orbit of *Venus*, T L a Portion of the Orbit of the *Earth*, in which the *Earth* is at T, and let *Venus* be in A in her ſuperiour *Conjunction* with the *Sun*; it is manifeſt in this Situation of theſe two *Planets*, that the Face of *Venus* which is illuminated by the *Sun*, is likewiſe turned towards the *Earth*; and then *Venus* will appear to us like a full, lucid Circle, as the *Moon* does at Full: But when ſhe has gone from thence to the Poſition B, ſome part of her obſcure Hemiſphere will be turned towards the *Earth*, and will loſe ſomething of her Fulneſs, and ſeem to us to be gibboſe. When *Venus* comes to the Poſition C, but half her illuminated ſide is turned towards the *Earth*, and then ſhe is ſeen like a half Circle, as the *Moon* is when ſhe enters in her firſt or laſt Quarter. But *Venus*, when ſhe arrives at the Poſition D, has but a ſmall part of her illuminated ſide turned towards the *Earth*: And becauſe ſhe is of a ſpherical Figure, which to us, becauſe of its great diſtance, appears like a Plane; the illuminated part which we ſee will appear to end in Points or Horns, whoſe Direction is always oppoſite to the *Sun*. But *Venus*, when ſhe is in the Poſition E, that is, in her inferiour *Conjunction* with the *Sun*, has her dark ſide totally turned towards the *Earth*, and then ſhe quite diſappears, unleſs ſhe

ſhe happen to be in her *Node*, or near it; then ſhe will appear like a black Spot to paſs over the Body of the *Sun*; which delightful Spectacle was never ſeen by mortal Eyes but once; and it was our Countreyman Mr. *Horrox*, who alone enjoy'd that Pleaſure. *Venus* will undergo the ſame *Phaſes* while ſhe paſſes through F, G to H. *viz.* about F ſhe is horned, in G a half Circle, in H gibboſe, and in A again full.

THESE Appearances of *Venus*, though they are not to be diſcerned by the naked Eye, yet they are diſtinctly and plainly to be perceived with a Teleſcope. Before the Invention of this noble Inſtrument, when *Copernicus* firſt revived the ancient *Pythagorean Syſtem*, and propoſed it to the Learned in *Aſtronomy*, to whom he maintained, that the *Planets*, among which he reckon'd the *Earth*, did move round the *Sun*, which was immoveable in the Center; it was objected to him, That if the Motions of the *Planets* were ſuch as he ſuppoſed them to be, that then *Venus* ought to undergo the ſame Changes and *Phaſes* as the *Moon* does. *Copernicus* anſwer'd, That perhaps the *Aſtronomers* in after-Ages would find, that *Venus* does really undergo all theſe Changes. This Prophecy of *Copernicus* was firſt fulfilled by that great *Italian* Philoſopher *Galileus*, who directing his Teleſcope to *Venus*, obſerved her Appearances to emulate the *Moon*, as *Copernicus* had foretold: And theſe Obſervations did ſurprizingly confirm the old Syſtem revived by *Copernicus*.

The Prophecy of Copernicus.

Theſe Phaſes *firſt obſerved by* Galileus.

IF the Centers of the *Sun* at S, *Earth* at T, and one of the inferiour *Planets* at O be joined with Lines, they will form the Triangle TSO: And if through the Center of the *Planet* there paſſes two Planes, one perpendicular to the Line TO, and the other to the Line SO; the one will cut off the Hemiſphere which is turned towards the *Earth*; the other, that which is turned towards the *Sun*, and by him illuminated. And the exteriour Angle of the Triangle TSO, which is at the *Planet*; that is, the Angle POS, will be equal to the

Plate XIII. Fig. 4.

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the Angle m O q, which measures $m\ q$ the Portion of the illuminated Semicircle that is turned towards the *Earth*. For the Angle S O r is a Right Angle, and so is the Angle m O T, which are therefore equal; but the Angles r O P and p O q are likewise equal, being vertical to each other; and therefore taking away Equals from Equals, there will remain the Angle S O P, equal to the Angle m O q; which Angle is measured by the Arch $m\ q$. And therefore the part of the illustrated Semicircle which is towards the *Earth*, and is to be seen from thence, does always measure the exteriour Angle S O P of the Triangle S O T. Now this Arch as seen from the *Earth* is projected into its own Versed Sine upon the Disk, as we shewed before in the *Moon*. And hence the Illumination of *Venus* seen from the *Earth*, is to her full and total Illumination, all other things remaining the same, as the Versed Sine of the exteriour Angle at *Venus* is to the Diameter of the Circle.

The Quantity of Illustration.

ALTHOUGH *Venus* in A shines upon the *Earth* at T with a full Face or Orb, yet she does not appear there with her greatest Brightness and Lustre; for her Splendor is diminished on the account of her greater distance from the *Earth*; and it is lessened in a greater Proportion than the conspicuous part of the illuminated Disk is encreased. For the Lustre of *Venus* decreases in the duplicate Proportion of the distance increased. But the visible illuminated part of her Face encreases only according to the versed Sine of the Angle S O P; and therefore the great Brightness of *Venus* is not when she is in A, but rather when she is about O. For suppose *Venus* at O four times nearer the *Earth* than when she is in A; in that case every determined part of the illuminated Disk will give sixteen times more Light than the same part does at A: but in O it may happen that only a fourth part of the illuminated Disk can be seen from the *Earth*; and therefore the Brightness of *Venus* is more encreased by her distance being diminished, than the same Brightness is lessened

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on account of a smaller Portion of her illuminated Disk being visible from the *Earth*.

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IF you desire to know in what Position *Venus* appears with the greatest Lustre, the great *Geometer* and *Astronomer*, Dr. *Edmund Halley* my Collegue, has given us an elegant Solution of this *Problem* in the *Philosophical Transactions*, Numb. 349. wherein he has shewn that *Venus* is brightest when she is about 40 Degrees removed from the *Sun*; and that then but only a fourth part of her lucid Disk is to be seen from the *Earth*. And in this Situation *Venus* has been many times seen in the Day-time, even in full Sun-shine. This Beauty and Brightness of *Venus* is very admirable, who having no native Light of her own, and only enjoying the borrowed Light of the *Sun*, should yet break out into so great a Lustre, that the like is not to be observed in *Jupiter*, nor even in our *Moon*, when she is in the same Elongation from the *Sun*. 'Tis true, the *Moon*'s Light is much greater, upon the account of her apparent Magnitude, than that of *Venus*; yet it is but a dull, and as it were, dead Light, which has nothing in it of that Vigour and Briskness that does always accompany the Beams of *Venus*.

Where the Illustration is greatest.

IF the Plane of the Orbit of *Venus* coincided perfectly with the Plane of the Ecliptick, *Venus* would always seem to move in the *Ecliptick*, and no where recede from it. But *Venus*'s Orbit does not lie in the Plane of the Ecliptick, but is in a Plane which is inclined to it, in an Angle of 3 Degrees and 24 Minutes, and cuts the Plane of the Ecliptick in a Line which passes through the *Sun*'s Center, that is called the *Line of the Nodes*. And the two Points, where the Orbit of the *Planet* produced cuts the Ecliptick, are named the *Nodes*. And therefore *Venus* is never seen, either from the *Sun* or the *Earth*, in the Ecliptick, but when she is in the *Nodes*; in all the other Points of her Orbit she is sometimes nearer to the Ecliptick, sometimes further from it; and seen from the *Sun*, she makes her greatest Excursion when she is 90 Degrees distant from both the *Nodes*.

The Plane of Venus's *Orbit does not lie in the Ecliptick.*

The Line of the Nodes.

Lecture XV.

Let TAB be a Circle in the Plane of the Ecliptick, LnVN the Orbit of *Venus*, cutting the Plane of the Ecliptick in the Line nN; we must conceive, the one half of this Orbit of *Venus* nLN, to be raised, or to stand above the Plane of the Ecliptick, and the other half nVN to fall below that Plane; and when *Venus* is in N or n, she is then in the Ecliptick: But when she arrives at P, she is seen to deviate from it; but in L, the Arch NL being a Quadrant seen from the *Sun*, she appears to recede the furthest from the Ecliptick; and this Point L is called the *Limit*, determining her greatest Excursion: for from thence departing, she again approaches the Ecliptick. If from the Place of *Venus*, as in P, we let fall on the Plane of the Ecliptick a Perpendicular PE, and draw SE, the Angle PSE will measure the distance of *Venus* from the Ecliptick, which is called *Venus*'s *Heliocentrick Latitude*, or such as it is seen from the *Sun*. Now this Latitude, having the place of the *Planet* in its Orbit, is thus investigated: Let the Arch NE be a Portion of the Ecliptick, NP a Portion of the *Planet*'s Orbit produced to the Heavens: Let P be the Place of *Venus*, N the *Node*; and let a Circle pass through the place of the *Planet* perpendicular to the Ecliptick; the Arch PE of this Circle, intercepted between the *Planet* and the Ecliptick, is the distance of the *Planet* from the Ecliptick, or the Measure of the Angle PSE. Now in the spherical Rectangular Triangle PNE, besides the Right Angle at E, we have the Side NP, the distance of the Planet from the *Node*, also the Angle N the Inclination of the Plane of the Orbit to the Ecliptick; wherefore by *Trigonometry* we can find out PE, which is the *Heliocentrick Latitude* of the *Planet*. This *Heliocentrick Latitude*, when the *Planet* comes to the same Point of its Orbit, is always the same and unchangeable: But the *Geocentrick Latitude*, or the distance of the Planet from the Ecliptick, as it is seen from the *Earth*, even though the *Planet* be in the same Point of her

Plate XIII. Fig. 5.

The Heliocentrick Latitude.

The Geocentrick Latitude.

her Orbit, is not constantly the same, but alters according to the Position of the *Earth*, in respect to the *Planet*. For let B T A *t* be the Orbit of the *Earth*, *n* P N, as before, the Orbit of the *Planet*, which suppose to be at P; from which let fall on the Plane of the Ecliptick the Perpendicular P E: in whatever part of her Orbit the *Earth* is, this Line P E will always subtend the Angle which measures the *Geocentrick Latitude* of the *Planet*. Suppose therefore the *Earth* at T, and *Venus* in P, where she comes nearest to the *Earth*; in which position *Venus* is seen in her inferiour *Conjunction* with the *Sun*, and her *Geocentrick Latitude* is measured by the Angle P T E. But if *Venus* should be in the same Situation P, and the *Earth* were at *t*, and from thence *Venus* were observed in her superiour *Conjunction* with the *Sun*, where she is at her greatest distance from us, her *Geocentrical Latitude* would be answerable to the Angle P*t*E, which is much less than the Angle P T E; because the distance P *t* is greater than P T. What we have here said of the Latitude of *Venus*, is likewise true of that of *Mercury*, and upon the same Account. Hence it is plain, that the inferiour *Planets*, all other things remaining the same, have a greater Latitude when they are near the *Earth*, than when they are further off. And it may happen that the *Geocentrical Latitude* of *Venus* may be greater than her *Heliocentrick*, which will be when she is between the *Sun* and the *Earth*, and she is nearer to us than to the *Sun*. But *Mercury* keeping always at a greater distance from the *Earth* than he has from the *Sun*, his *Geocentrick Latitude* will constantly be less than his *Heliocentrick*, which when at the biggest is about 7 Degrees; for so much is the Inclination of his Orbit to the Plane of the Ecliptick.

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Plate XIII. Fig. 6.

SINCE none of the Orbits of the *Planets* lie in the Plane of the Ecliptick, but all of them cut it in a Line passing through the *Sun*, no *Planet* can be above twice in the time of its Period in the Ecliptick, which is when they are in their

Lecture XV. *Nodes*; at all other times every one of them will deviate some more, some less, from the said Plane of the Ecliptick: But yet there are certain determinate Boundaries which they never transgress. And therefore if we imagine in the Heavens a Zone, or broad Circle of 20 Degrees breadth, that is, 10 Degrees on each side of the Ecliptick which lies exactly in the middle of this Space or Zone; such a Space will constantly contain all the *Planets* in its Compass, and is called the *Zodiack*, from the Images of living Creatures, or the Constellations which fill that part of the Heavens: The *Earth* keeping always, as it were, in the King's Highway, never turns out from its Course in the Ecliptick, but the *Moon*, and the other five Wanderers will make Excursions from it, for several Degrees, sometimes to the *North-side*, and sometimes to the *South-side* of the Ecliptick; and yet they always keep within the Bounds of the *Zodiack*.

The Zodiack.

The Motion of Venus *in the* Zodiack.

HITHERTO we have considered the Motions and *Phases* of *Venus*, as they have a Relation to the *Sun* and *Earth*; let us next consider the Motions of *Venus* in the Heavens, as they are observed from the *Earth*, and the Way she takes in the *Zodiack*. For which purpose let A B C be the Orbit of *Venus*, T G F the Orbit of the *Earth*, the Circle L M O the *Zodiack* among the *fixed Stars*: and, first, suppose the *Earth* in T, and *Venus* in A, near her superiour *Conjunction* with the *Sun*; it is evident, that a *Spectator* on the *Earth*, will see *Venus* at A, as if she were in the Point of the *Zodiack* L: if the *Earth* had no Motion while *Venus* moves from A to B in its Orbit, it would seem to describe the Portion of the *Zodiack* L M: But in the mean time the *Earth* also moves; and when *Venus* is in B, the *Earth* is come to the Point of its Orbit H; from whence the *Spectator* looking upon *Venus* at B, observes her in the *Zodiack* at N; so that she will seem to have run through the Space L M N in the *Zodiack*: and *Venus* will appear to have gone more *Eastward* than

Plate XIII. Fig. 7.

than she would have done, had the *Earth* stood still without any Motion in its Orbit. But when *Venus* comes to C, the *Earth* has moved on to G; so that *Venus* is seen in the Line GO drawn from the *Earth*, which touches her Orbit; in which Position her apparent Motion in the *Zodiack* will be very nearly equal to the apparent Motion of the *Sun*: From thence let *Venus* move on from C to A, and in that time the *Earth* will have come from G to K, and then *Venus* will be seen near her inferiour *Conjunction* with the *Sun*; in which Position she will be observed in the *Zodiack*, as if she were at P: but before she was seen at O, and therefore she will here appear to have gone backwards in the *Zodiack* through the Arch OP, or to have moved from the *East* to the *West*, contrary to the Order of the Signs. And because in C she was observed to go *Eastwards* as fast as the *Sun* does; but in A she is seen to have a quick Motion backward: There must be some place of her Orbit between C and A, where she appears to us neither to go forward nor backward, but to stand still, and continue in the same place in the Heavens: In which case she is said to be *Stationary*, or to stand still.

Lecture XV.

Venus *Direct.*

Venus *Retrograde.*

Venus *Stationary.*

LET *Venus* now arrive at E, and the *Earth* at the Point of its Orbit F, *Venus* will then be seen in the Point of the Ecliptick Q, and will appear to have moved further backwards in the Ecliptick, or towards the *West*. But when *Venus* is seen from the *Earth* in a Line which touches her Orbit, she will then seem to have a progressive Motion, equal to the apparent Motion of the *Sun* from *West* to *East*: And because before, her apparent Motion was backward, or from *East* to *West*, and now forward the contrary way, from *West* to *East*, there must be some place between the two contrary Motions, where she will neither appear to go backwards nor forward; but for some time to stand still, and keep the same Position in the Heavens. While the *Earth* comes to D, and *Venus* arrives at C, she will appear in that time

to

Lecture XV.

to have moved through the Arch Q R of the *Zodiack*, and to have a quicker Motion towards the *East*. Hence *Venus*, when ſhe is in her ſuperiour *Conjunction* with the *Sun*, is always ſeen to move directly according to the Order of the Signs; but when ſhe is in her inferiour *Conjunction*, and between the *Earth* and the *Sun*, then ſhe is ſeen to have a backward Motion, and to be carried againſt the Order of the Signs, from *Eaſt* to *Weſt*.

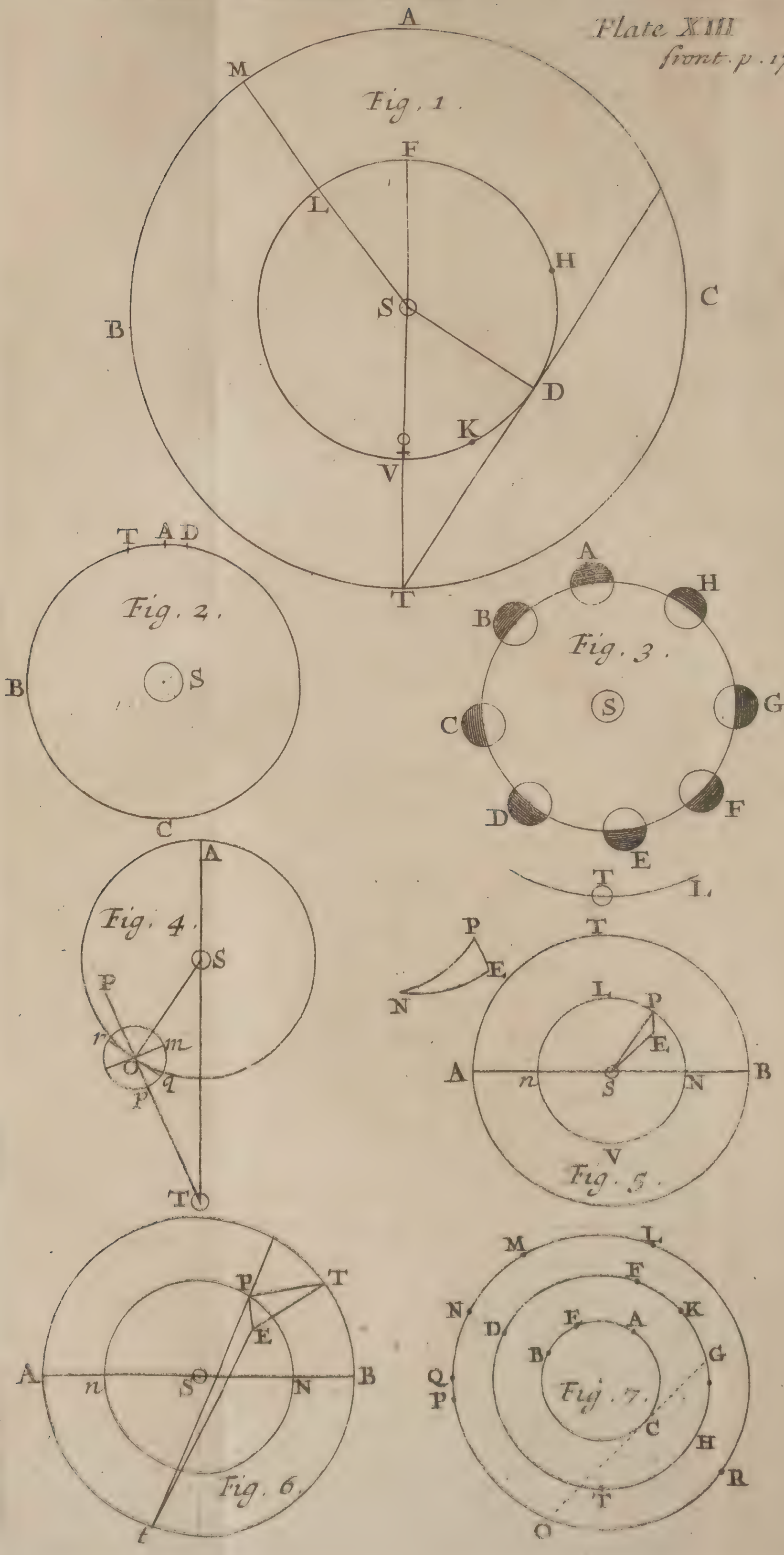
The Appearances of Mercury *like thoſe of* Venus.

WHATEVER we have demonſtrated concerning the Motions of *Venus*, is likewiſe true, and to be underſtood of the Motions of *Mercury*; but the *Conjunctions* of *Mercury* with the *Sun*, his Directions, Stations and Retrogradations, are more frequent than in *Venus*; for *Mercury* circulating faſter, and in a leſſer Orbit than *Venus*, does oftner overtake the *Earth* than ſhe. Hence it is plain, that the Motions of theſe two *Planets* ſeen from the *Earth*, are very irregular and unequal; ſince they are ſometimes ſeen to have a Motion forward; ſometimes they appear immoveable or ſtationary, after this they change their Courſe, and move backwards, and after ſuch a Regreſſion they again take up their Stations, and keep for ſome time the ſame place in the *Zodiack*. Whereas a *Spectator* in the *Sun* will always obſerve theſe *Planets* to go forward with a Motion regulated after a certain Rate. For the apparent Inequality of theſe Motions ſeen from the *Earth*, is ſuch as exactly anſwers to a regular Motion round the *Sun*. And therefore it is manifeſt, that the *Sun*, and not the *Earth*, is the Center of theſe *Planets* Motion.

The Orbits of Mercury *and* Venus *Elliptical.*

WE ſhewed before, that the Orbit of the *Earth* was not a Circle, but an Ellipſe; the ſame thing is true of the Orbits of *Venus* and *Mercury*, and of all the other *Planets*, which are really Ellipſes and not Circles, that have one common *Focus* in which the *Sun* reſides, about whom the *Planets* perform their Circulations with Motions; which though not perfectly equable, yet they are all regulated

Plate XIII
front. p. 170



gulated by a certain, unchangeable and constant Law, which none of them transgress; for every *Planet* moves in the *Perimeter* of his own Ellipse, so that the Line or Ray passing from its Center to the Center of the *Sun*, does always describe or sweep an Elliptick Space or *Area* proportional to the Time; or which is the same thing, in equal time it sweeps an equal *Area*. Hence the *Planets* must move more slowly in their *Aphelia*, and quicker in their *Perihelia*: And these *Aphelia* are not like the *Apogeon* of the *Moon*, but they are either at rest without Motion, or if they have any, it is so slow, that it is not easily perceived in the time of a Man's Age. And here it is to be observed, that of all the *Planets*, *Mercury* has the most Excentrick Orbit; for therein the Excentricity is to the mean distance as 2051 to 10000. Lecture XVI.

LECTURE XVI.

Of the Motions of the three superiour Planets, Mars, Jupiter *and* Saturn, *and the Appearances arising from them.*

WE have now dwelt long enough on the Explication of the Motions of the two inferiour *Planets*; let us next contemplate the superiours. For which purpose let ABCT be the Orbit of the *Earth*, and let *Saturn*, *Jupiter* and *Mars* turn round the *Sun* in different Orbits at their proper distances, and perform their Circulations, each in its proper Period; and let PQV be a Portion of the *Zodiack* in which these *Planets* are observed to perform their Motions. *First*, It

These superiour Planets *may have any Position or Aspect in respect of the* Sun.

Plate XIV. Fig. 1.

Lecture XVI.

It is plain, that all these *Planets* seen from the *Sun*, may be observed either in *Conjunction* with the *Earth*, or in *Opposition* to it. Thus *Saturn* may be in ♄ when the *Earth* is in M, in the Line which joins the Centers of the *Sun* and *Saturn*; in which Case the *Earth* and *Saturn* from the *Sun* are seen in *Conjunction*: But the *Earth* may likewise be in the same Right Line produced the contrary way, as in B, where from the *Sun* these two *Planets* will be seen in *Opposition* to each other. But in this Situation, the *Sun* seen from the *Earth*, will appear to be in *Conjunction* with *Saturn*. *Secondly*, It is evident, that these *Planets* seen from the *Earth*, may have any Aspect, or obtain any Position in respect to the *Sun*, and may have any desired Elongation from him; which cannot be in the inferiour *Planets*, who are always confined to the Neighbourhood of the *Sun*. For from the *Earth* T there may be drawn a Line T P, which will cut all the Orbits of the superiour *Planets*, and may make with T S the Line which joins the *Sun* and *Earth*, any Angle required, as S T P. And therefore when the *Earth* is in T, *Saturn* may be in F, whose Elongation from the *Sun* will then be the Angle S T F. Moreover, when the *Earth* and any superiour *Planet* are seen from the *Sun* in *Conjunction* together, that *Planet* observed from the *Earth*, will appear in *Opposition* to the *Sun*; and an Inhabitant of our Terraqueous Globe, will see the *Sun* and it, in opposite Parts of the Heavens.

The times between two Conjunctions, *or two* Oppositions *in the superiour* Planets.

LET now any superiour *Planet*, as for Example, *Saturn*, be seen from the *Sun* in *Conjunction* with the *Earth*: After *Conjunction*, the *Earth* having a quicker angular Motion than *Saturn*, an Inhabitant or *Spectator* in the *Sun* will see the *Earth* daily to recede more and more from *Saturn*. And because the *Earth*, according to its mean Motion, does every Day describe an Arch of the Ecliptick of 59 Minutes 8 Seconds, and *Saturn* moves only 2 Minutes in a day, the *Earth* will appear from the *Sun* to recede every Day from *Saturn* the space

of

of an Arch of 57 Minutes 8 Seconds. If we ſay then, As 57 Minutes 8 Seconds is to 360 Degrees, or to 21600 Minutes, ſo is one Day to a fourth Quantity; we ſhall have the Number of Days in which the *Earth* will be again obſerved from the *Sun* to be in *Conjunction* with *Saturn*, which is 378 Days. But when the *Earth* and *Saturn* are ſeen from the *Sun* in *Conjunction*, the *Sun* and *Saturn* from the *Earth* appear in *Oppoſition*. And therefore the time between two *Oppoſitions* of the *Sun* and *Saturn*, immediately following one another, computed according to their middle Motions, is 378 Days, or one Year and 13 Days. And there is the ſame time between two *Conjunctions* of *Saturn* and the *Sun* ſeen from the *Earth*, or between any two ſimilar Aſpects or Elongations from the *Sun*. And the time between the *Oppoſition* and *Conjunction* of *Saturn* with the *Sun*, is the half of this time, or 189 Days.

Lecture XVI.

BY the ſame Method we ſhall find, that the time between two *Conjunctions* or *Oppoſitions* of *Jupiter* and the *Sun* conſiſts of 398 Days, or a Year and 33 Days. But *Mars* after an *Oppoſition*, does not again come into the ſame Situation, till after 2 Years and 50 Days.

WHEN the *Planets* are in *Oppoſition* to the *Sun*, they riſe when the *Sun* ſets; and ſet when he riſes; and then after their Departure from the *Oppoſition* to the *Sun*, they remain to the *Eaſtward* of the *Sun*; and after Sun-ſet they are to be ſeen in the Evening, till they come in *Conjunction* with him, when they ſet and riſe together. Afterwards, as they recede from the *Sun*, they become more *Weſterly* than he, and are then only to be ſeen in the Morning before the *Sun* is up; for in the Evening they ſet before the *Sun*, till they at laſt come to be oppoſite to the *Sun*, when again they riſe at Sun-ſet.

The Planes of their Orbits are inclined to the Ecliptick.

AS in the inferiour *Planets*, ſo the ſuperiour have not their Orbits in the Plane of the Ecliptick; for the Planes of all their Orbits cut the Plane of the Ecliptick in Lines which paſs through the

Sun,

Lecture XVI. Sun, which are called, the *Lines of the Planets Nodes*: And the Points where these Lines meet with the Ecliptick, are called the *Nodes*. And therefore the superiour *Planets* are never precisely in the Ecliptick, but when they are in the *Nodes*: In all the other Points of their Orbits they are further or nearer to the Ecliptick, according to their Distance from the *Nodes*; and their Distances are greatest when they are at equal Distances from both *Nodes*; which Points are called the *Limits*, where the greatest *Heliocentrick* Latitudes which measure the Inclinations of the Orbits to the Ecliptick, are as followeth; *Saturn*'s greatest *Heliocentrick* Latitude is 2 Degrees 30 Minutes. *Jupiter*'s is 1 Degree 20 Minutes, and that of *Mars* is 1 Degree and 52 Minutes.

The Heliocentrick *and* Geocentrick *Latitudes.* HAVING the Place of a *Planet* in its Orbit, or, which is the same thing, its Distance from the *Node*, by the same Method we find out its *Heliocentrick* Latitude, as we did in the inferiour *Planets Mercury* and *Venus*. But the *Geocentrick* Latitudes, or the Distances of the *Planets* from the Ecliptick, as they are seen from the *Earth*, depend much upon the Position and Distance of the *Earth*. For where the *Heliocentrick* Latitude continues the same, yet according to the various Positions the *Earth* may have, the visible Latitude of a *Planet* seen from thence, will be various. For let T ♉ *t* be the Orbit of the *Earth*; and the Orbit of any superiour *Planet*, as for Example, that of *Mars*, suppose to be ♂ M, whose Plane is inclined to the Ecliptick, and cuts it in the Line of *Nodes n* N. Let *Mars* be in ♂, and the *Earth* in T, so as *Mars* may be observed in *Opposition* to the *Sun*; and from ♂ let fall on the Plane of the Ecliptick the Perpendicular ♂ E; this Line will subtend the Angle which measures the *Geocentrick* Latitude. And therefore when the *Earth* is in T, the visible Latitude is measured by the Angle ♂ T E. But if the *Earth* was in *t*, so that *Mars* was seen in *Conjunction* with the *Sun*, its visible Latitude will be the Arch which measures the

Plate XIV. Fig. 2.

Angle

Angle ♂ t E, which is much leſs than the Angle ♂ T E, and is nearly leſs in the ſame Proportion as the Diſtance T ♂ is leſs than the Diſtance t ♂. When the *Earth* is in T, the *Geocentrick* Latitude of *Mars* is greater than its *Heliocentrick*; but when it is in t, the *Heliocentrick* is greater than the *Geocentrick*; and according to the various Poſitions of *Mars* and the *Earth*, his viſible Latitude will be changeable; ſo that all other things being alike, the Latitude is greater, the nearer he comes to the *Oppoſition* of the *Sun*, and the leſs, as he approaches to a *Conjunction* with the ſame. Lecture XVI.

IT is alſo evident, that none of the ſuperiour *Planets* can be ſeen from the *Earth* in the *Sun*'s Disk, as the inferiour *Mercury* and *Venus* are; but yet they may be all of them covered by the *Sun*, and lie hid behind him, when they come in *Conjunction* with him, and are near their *Nodes*.

Jupiter *and* Saturn *have always a round full Face.*

SINCE the Faces of all the *Planets* which are turned towards the *Sun*, ſhine only with a reflected and borrowed Light; and becauſe the *Earth* ſeen from *Jupiter* or *Saturn*, is always to be obſerved near the *Sun*'s Body, the Faces of theſe *Planets*, which are turned towards the *Sun*, will alſo be towards the *Earth*; whence the Inhabitants of our Globe do always behold theſe *Planets* ſhining in full Orbs or Circles. But *Mars* having an Orbit, which lies very near the *Earth*, its Face which is towards the *Sun*, will not always be totally turned towards the *Earth*; but when in his Quadrature, or when there is about a fourth part of the Ecliptick between the *Sun* and him, as ſuppoſe the *Earth* in M or B, and *Mars* in N or R, then ſome part of the illuminated Face will be turned from the *Earth*, and therefore *Mars* will not appear in a compleat Circle, but will be ſeen as deficient or gibboſe; but when he comes to be in *Conjunction* or *Oppoſition*, he then re-aſſumes his round Figure, his illuminated Face being totally turned towards the *Earth*; and particularly when in *Oppoſition* to the *Sun*, he looks brighteſt and biggeſt.

Mars *in his Quadrature, gibboſe.* Plate XIV. Fig. 1.

FOR

Lecture XVI.

In Opposition *the superiour* Planets *are biggest.*

FOR all the superiour *Planets* appear much bigger when they are in *Opposition* to the *Sun*, than when they are in *Conjunction*, being much nearer to the *Earth* in the one Position than in the other; insomuch that the Difference of their Distances in these two Positions, is as great as the Diameter of that Orb in which the *Earth* goes round the *Sun*; which Difference bears a considerable Proportion to the Distance of *Mars* from the *Sun*, and greater than it does to the Distances of the other *Planets*; and therefore will produce a great difference in his apparent Magnitude: For *Mars* is five times nearer to us when he is in *Opposition*, than when he is in *Conjunction* with the *Sun*. And therefore since the visible Disk and Lustre of a *Planet* increases in a duplicate Proportion of that wherein the Distance is diminished, *Mars* will appear 25 times bigger and brighter when he is in *Opposition*, than when he is in *Conjunction* with the *Sun*.

The apparent Diameter of the Sun *seen from* Jupiter *and* Saturn.

BECAUSE *Jupiter* is five times further off the *Sun* than the *Earth* is, the apparent Diameter of the *Sun* seen from *Jupiter*, will be five times less than it is seen from the *Earth*, and will be no bigger than 6 Minutes, which to us is 30 Minutes. And the Disk of the *Sun* will appear 25 times less to the Inhabitants of *Jupiter*, than it does to us, who will likewise receive but the 25th part of the Light and Heat from him that we enjoy. But *Saturn* being 10 times further from the *Sun* than we, the apparent Diameter of the *Sun* seen from him, will be no bigger than 3 Minutes, and will be but little more than twice the Diameter of *Venus*, when she approaches nearest to the *Earth*: And therefore the Disk of the *Sun*, as it would appear to a *Saturnian Astronomer*, will be 100 times less than we see it; and both its Light and Heat are there diminished in the same Proportion; and therefore the warmest Regions in *Saturn*, even under his Æquator, are much colder than our Frigid Zones.

Their Degrees of Heat compared with our Heat which we receive from the Sun.

ALL

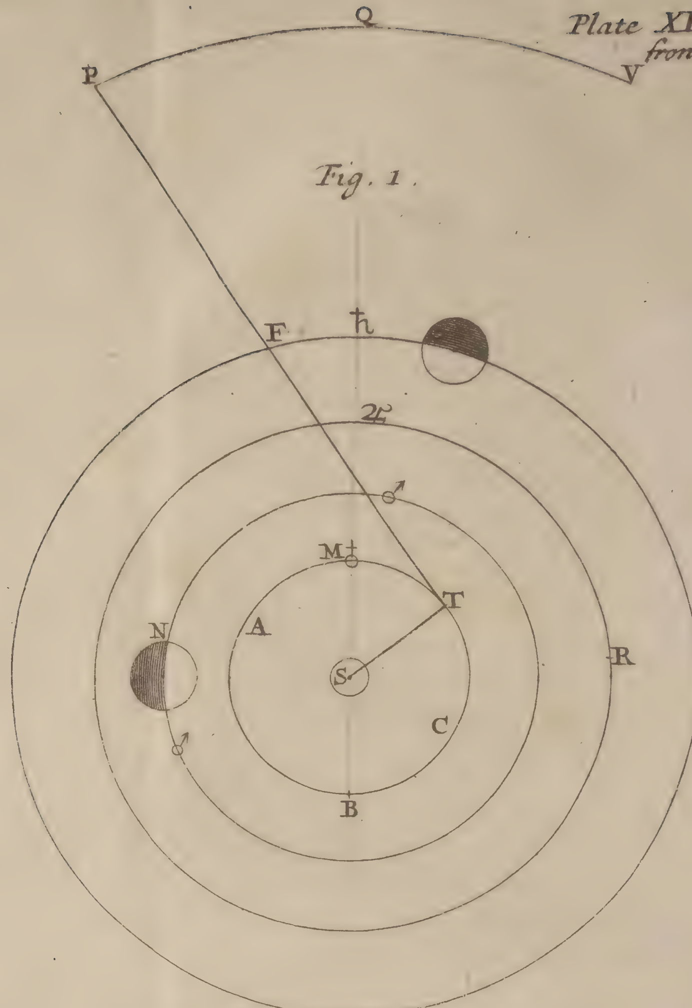


Fig. 1.

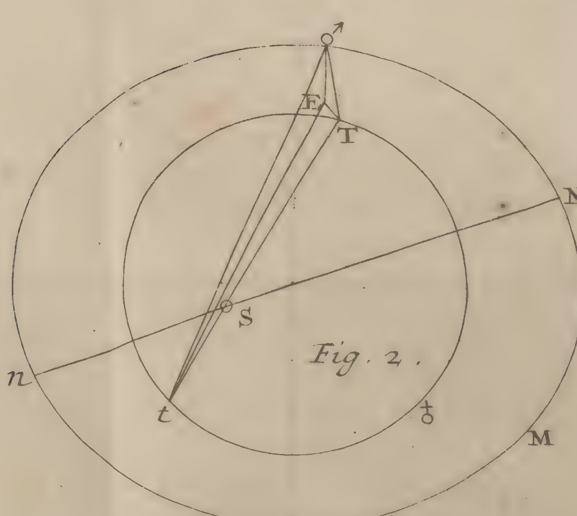


Fig. 2.

ALL the superior *Planets* observed from the *Sun*, will appear to move regularly the same way, and to proceed in their Orbits according to the same Law, which is the equable Description or Sweeping of Elliptick *Area's* round the *Sun*; by which means their angular Motions round the *Sun* will appear somewhat unequal; for in their *Aphelia* they proceed more slowly; in coming to their *Perihelia* they accelerate their Motions. But these *Planets* observed from the *Earth*, have very different Appearances, and irregular Motions in the *Zodiack*; sometimes they seem to move forward from *West* to *East*, according to their real Motions; then they by degrees slacken their Pace, till at last they lose all their Motion, and seem to stand still. After some small time they are again set a moving, but seem to take a contrary course to what they had before, and go backwards, directly in Opposition to their real and true Motions: And thus having for some way gone backward, or from *East* to *West*, they come again to be immoveable and stationary. These great Changes of their Courses and Motions are not real in the *Planets*, but are occasioned by the Motion and Position of the *Earth*, from whence the *Astronomer* observes them.

Lecture XVI.

The Motions of the Planets *seen from the* Sun, *are very regular.*

But from the Earth *they are observed to be very irregular.*

LET PQO be a Portion of the *Zodiack*, ABCD the Orbit of the *Earth*, EMGHZ the Orbit of a superiour *Planet*; for Example, of *Saturn*: and suppose the *Earth* in A, and *Saturn* in E; in which Position he will appear in the *Zodiack* at the Point O. If *Saturn* remained there without any Motion of his own, when the *Earth* comes to B, he would be seen in the Point of the *Zodiack* L, and would appear to have described the Arch of the *Zodiack* O L, and to have moved according to the Order of the Signs, from *West* to *East*. But because in the mean time, while the *Earth* is passing from A to B, *Saturn* does likewise move in his own Orbit from E to M, where he is seen in *Conjunction* with the *Sun*, he will appear to have described the Arch of the *Zodiack* O Q,

Plate XV. Fig. 1.

Lecture XV.

When the superiour Planets *are direct and swift.*

which is greater than the Arch O L: whence the superiour *Planets*, when they are in *Conjunction* with the *Sun*, appear to have a Motion forward much quicker than at other times, and that for a twofold Cause; which is, because they really have a Motion forward from *West* to *East*, and likewise because the *Earth*, in the opposite part of the Heavens, is carried the same way round the same Center. And therefore these *Planets*, when they are at their greatest Distance from us, and in *Conjunction* with the *Sun*, appear to have a quicker Motion than usual to the *East*, according to the Order of the Signs: In which Position a *Planet* is said to be direct, or to have a direct Motion. When the *Earth* comes to C, while *Saturn* describes the Arch M G, he will then be observed in the *Zodiack* at R. But the *Earth* being advanced to K, and *Saturn* to H, so as the Line K H joining the *Earth* and *Saturn* continue for some time parallel to itself, or very nearly so; then our *Astronomers* will observe *Saturn* all that while in the same Point of the *Zodiack* at P, and with the same *fixed Stars*, he then appearing Stationary. But the *Earth* being come to D, and *Saturn* coming into *Opposition* to the *Sun* in X, he will appear in the *Zodiack* at V, and will seem to have gone backwards through the Arch P V. And therefore the superiour *Planets*, when they are in *Opposition* to the *Sun*, are always Retrograde, or appear to have a backward Motion from *East* to *West*, which is contrary to the Order of the Signs: But when the *Earth* comes again to A, and *Saturn* remaining near to Z, again that *Planet* will seem there to occupy his Station, and to remain without Motion. At last, after the *Earth* has left that Situation, *Saturn* will appear to begin again to move forward.

When stationary.

What we have here shewed concerning *Saturn*, is likewise to be understood of *Jupiter* and *Mars*, who are likewise observed to have all these Variations and Changes in their Motions, as sometimes

times to move quickly forwards, then to ſtand ſtill, and after that to fall backward; then again they become ſtationary, and in a ſhort time after they go forward with a direct Motion. But the Regreſſions or backward Motions of *Saturn*, are more frequent than thoſe of *Jupiter*; becauſe the *Earth* more frequently overtakes *Saturn*, whoſe Motion is ſlower than *Jupiter*'s, who is not a little quicker in his Motion. And for the ſame Reaſon *Jupiter*'s Regreſſions do oftner happen than thoſe of *Mars*; becauſe *Mars* moving faſter, deſcribes a greater Space in the *Zodiack*; ſo that there is more time neceſſary for him to come in *Oppoſition* to the *Sun*, than what *Jupiter* needs for that purpoſe.

Lecture XVI.

When Retrograde.

Let AC be a Portion of the *Earth*'s Orbit, which is touched by the Right Line AN, in which we will ſuppoſe the ſuperiour *Planets* to be ſeen from the *Earth*, viz. *Mars* in ♂, *Jupiter* in ♃, and *Saturn* in ♄; and let KLMN be a Portion of the *Zodiack*. Then the place of *Mars* ſeen from the *Sun* is K, which is called his true or Heliocentrick Place. But an *Aſtronomer* on the *Earth* will obſerve him at the Point N, which is called his *Apparent* or *Geocentrick Place*; ſo likewiſe *Jupiter* ſeen from the *Sun*, appears in L, which is his true Place; but from the *Earth* his apparent Place is N. After the ſame manner the true Place of *Saturn* ſeen from the *Sun*, the Center of his Motion, is M; but his Place in the *Zodiack*, that is viſible from the *Earth* is N. The Arches KN, LN, MN, the Differences between the true and apparent Places of the ſuperiour *Planets*, are called the *Parallaxes* of the annual Orb in theſe *Planets*. Through the *Sun* S draw SO parallel to AN, and by the 29*th* of the 1*ſt* of *Euclid*, the Angles A ♂ S, A ♃ S, A ♄ S, will be reſpectively equal to the Angles KSO, LSO and MSO. But the Angle ANS is equal to the Angle NSO, whoſe Meaſure is the Arch NO, which will therefore be the Meaſure of the Angle ANS, which is the Angle under which the Semidiameter AS

The Parallax of the Annual Orb.

Plate XV. Fig. 2.

Lecture XVI.

of the *Earth*'s Orbit is ſeen from the Starry Heavens. But this Semidiameter is nothing in reſpect of the great Diſtance of the Heavens or Stars; for from thence it would appear under no ſenſible Angle, and look like a Point. And therefore in the Heavens the Angle N S O, or the Arch N O vaniſheth, and the Points N and O coincide; and the Arches K O, L O, M O, are of the ſame bigneſs with the Arches K N, L N and M N, which are therefore the Meaſures of the Angles A ♂ S, A ♃ S, A ♄ S. But theſe Angles are as the apparent Semidiameters of the Orbit of the *Earth* ſeen from the reſpective *Planets*: And therefore in each of the ſuperiour *Planets* the *Parallax* of the Annual Orbit is equal to the Angle under which the Semidiameter of the Earth's Orbit is ſeen from that *Planet*; and the nearer any of them is to the *Earth* or *Sun*, ſo much the bigger is that Angle: And therefore this *Parallax* in *Mars* is greater than in *Jupiter*; and again, in *Jupiter* greater than it is in *Saturn*. But in the *fixed Stars* there can be no *Parallax* of the Annual Orb obſerved, it being ſo very ſmall.

The Retrogreſſions of Mars *greater than thoſe of* Jupiter; *and* Jupiter's *greater than* Saturn's.

IT is alſo evident from hence, that the Retrogreſſions of *Mars* are greater than thoſe of *Jupiter*, though they do not happen ſo often; ſo likewiſe *Jupiter* has his Retrogreſſions greater than thoſe of *Saturn*, and that upon a double Account: Firſt becauſe *Mars* is nearer to the *Earth* than *Jupiter*, and *Jupiter* nearer than *Saturn*; and likewiſe becauſe they move faſter.

HAVING the *Parallax* of the Annual Orb in any *Planet*, we can from thence eaſily find his Diſtance from the *Sun*, in reſpect of the *Earth*'s Diſtance from him: For in *Mars*, becauſe the Angle A ♂ S is given, being meaſured by the *Parallax* of the Annual Orb, and the Angle ♂ A S is found by Obſervation, being the viſible Elongation of *Mars* from the *Sun*: If we make the Proportion, As the *Sine* of the Annual *Parallax* is to the *Sine* of the Elongation, ſo let S A the Diſtance of the *Earth* from the *Sun* be to a Fourth, which will be

be ♂ S, the Diſtance of *Mars* from the *Sun*. This Annual *Parallax*, by which the *Planets* ſeem ſometimes to move faſter, ſometimes ſlower, in the Heavens, ſometimes to go *Eaſtward* and ſometimes *Weſtward*, produces in their Motions an Inequality, which, by the *Aſtronomers*, is called their *Second* or *Optical Inequality*, to diſtinguiſh it from their firſt Inequality which the *Planets* really have, by which they move in their Orbits with Motions that are not always the ſame. In the *Oppoſitions* or *Conjunctions* of theſe *Planets* with the *Sun*, this ſecond Inequality or *Parallax* vaniſhes; and their *Geocentrick* Places and the *Heliocentrick* coincide; or a *Spectator* in the *Sun*, and another in the *Earth* would obſerve the *Planet* in the ſame Point of the Heavens.

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THE Angles A ♂ S, A ♃ S, A ♄ S, are nearly the greateſt Elongations of the *Earth* from the *Sun*, if ſhe were obſerved from the reſpective *Planets*, when the Line N ♂ A touches the *Earth*'s Orb in A. In *Mars* the Angle A ♂ S is about 42 Degrees; and therefore the *Earth* ſeen from *Mars*, never goes ſo far from the *Sun* as we ſee *Venus* does. In *Jupiter* the greateſt Elongation of the *Earth* from the *Sun* will be obſerved to be but 11 Degrees, and therefore is not ſo much as half the Diſtance we obſerve *Mercury* to depart from the *Sun*. In *Saturn* the Angle A ♄ S, or the greateſt Elongation of the *Earth* from the *Sun* that can be ſeen from that *Planet*, is but 6 Degrees, and not much above a fourth Part of the greateſt Elongation we obſerve in *Mercury*. And ſince *Mercury* is but ſeldom ſeen by us, a ſight of the *Earth* from *Saturn* may be a rare and unuſual Spectacle: Perhaps the *Saturnian Aſtronomers* have not yet diſcovered, that there is ſuch a Body as our *Earth* in the Univerſe.

The Attendants or Satellits of Jupiter *and* Saturn.

EACH of the two outmoſt of the *Planets* have a good Company of Attendants; for *Jupiter* keeps no fewer than four conſtantly by him, and *Saturn* five in his Retinue, which is a Sight no leſs wonderful than delightful. Theſe *Satellits*, like our *Moon*, do always accompany their primary *Planets* in

Lecture XVI. their Circuits round the *Sun*; and in the mean time they perform their proper Circulations about their Primaries; and therefore they will have the same *Phases* and Figures that our *Moon* shews us: When they are in *Opposition* to the *Sun*, they appear to *Saturn* and *Jupiter* bright and full; from thence receding, they assume a gibbous Shape: When they come to a Quadrantile Aspect, they look like Half-Moons; before the *Conjunction* they shew themselves in horned Figures; and when they come to be joined in the same Line with the *Sun*, they totally disappear.

THESE *Satellits*, seen from the *Earth*, though they go, at the furthest, but a little way from their Primaries, yet sometimes they approach them nearer, and sometimes remove a little further from them. Let ABT be the Orbit of the *Earth*, in the middle of which the *Sun* resides. Let EF be a Portion of the Orb of *Jupiter*, in which let *Jupiter* be in ♃, who keeps in the middle of the Orbits of his four Attendants. These *Satellits* or *Moons*, when they describe the inferiour Parts of their Orbits LMN, seen from the *Earth* or *Sun*, will appear to have a Motion *Westward*; but while they are moving through the superiour Portions GHK, we observe them to move *Eastward*, according to their true Motions. Now when their visible Motion is *Eastward*, they are twice hid from us; once in O behind the Body of *Jupiter*, that is, in the Right Line which joins the Centers of the *Earth* and *Jupiter*; and again they vanish and become invisible when they fall into the Shadow of *Jupiter*, or are in the Right Line which joins the Centers of the *Sun* and *Jupiter*, and then they suffer Eclipses, which is always when they are at their Full, as seen from *Jupiter*: these Eclipses happening in the same manner as they do to our *Moon*, by the Interposition of the *Earth* between the *Sun* and it.

Plate XV. Fig. 3.

WHEN *Jupiter* is to the *East* of the *Sun*, and is seen in the Evening after Sun-setting, that is, when the *Earth* is in A, they are first hid behind

Jupite

Jupiter, because of their visible *Conjunction* with *Jupiter*, before they fall into his Shadow; and their second disappearing is in the Eclipse, upon their entring the Shadow. But when *Jupiter* is more *Westerly* than the *Sun*, as he appears after *Conjunction*, when he is only seen in the Morning, that is, when the *Earth* is about B, then they fall into *Jupiter*'s Shadow at V and are eclipsed, before they are hid behind his Body in P. But when these *Moons* have a Retrograde Motion, that is, when they are seen to go *Westward*, and describe the inferiour Parts of their Orbits, then they only once disappear in Q, when they cannot be distinguished from the Body of *Jupiter*: But when the *Satellits*, seen from the *Sun*, are in their inferiour *Conjunction* with *Jupiter*; or as seen from *Jupiter*, they are in *Conjunction* with the *Sun*, their Shadows will fall upon *Jupiter*; and some part of the Disk of *Jupiter* will be in an Eclipse; and a *Spectator* within the Shadow would observe a total Eclipse of the *Sun*. We have already given the Distances and Periods of all the *Jovial* and *Saturnian Moons*, at the End of our third Lecture.

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The Parallax *of the Annual Orb, and the Distance of* Jupiter *from the* Sun *determined by the Eclipses.*

BY the Motions and Eclipses of these *Moons*, the *Parallax* of the Annual Orb in *Jupiter*, and his Distance from the *Sun* may be easily known. For, let POR be the Orbit of any *Satellit*; for Example, the outermost; and suppose the *Earth* in the Point of its Orbit A, the time must be observed when the *Satellit* lies hid behind *Jupiter*'s Body in O: For which purpose the Moment of Time must be carefully mark'd when he first disappears, and then also the Moment he becomes again visible; the middle Moment between these two, is the time when the *Satellit* is in O, or in the Line which passes through the Centers of the *Earth* and *Jupiter*. After the same manner observe when the *Satellit* is in the middle of an Eclipse, or in the middle of *Jupiter*'s Shadow, that is, when it is in V; by this means we shall have the time it takes to describe the Arch OV. And because his Motion about *Jupiter* is equable, and his

Lecture XVI.

Periodical Time known, we can from thence find out the Arch O V; for this *Planet* revolves about *Jupiter* in 402 Hours. Let us ſuppoſe the time he takes to move from O to V be 12 Hours; ſay, As 402 Hours is to 12 Hours, ſo are 360 Degrees to a fourth Quantity, which will be found to be 10 Degrees 44 Minutes. And therefore the Arch O V is 10 Degrees 44 Minutes. But this Arch O V is the Meaſure of the Angle O ♃ V, or of the Angle which is equal to it A ♃ S; and the Arch which meaſures this Angle is the *Parallax* of the Annual Orb, which therefore is known. In the Triangle therefore A ♃ S we have the Angle at ♃, and alſo the Angle at A the Elongation of *Jupiter* from the *Sun*, which may be had either by a Calculation from Aſtronomical Tables, or by Obſervation. Beſides, we have the Side A S, the Diſtance of the *Earth* from the *Sun*, which we aſſume to conſiſt of 100000 Parts. Since therefore in this Triangle we have all the Angles and one Side, by *Trigonometry* we ſhall find the other Sides, and particularly S ♃ the Diſtance of *Jupiter* from the *Sun*; ſo likewiſe we may find A ♃ the Diſtance of *Jupiter* from the *Earth*, which is always variable. But for the nice Determinations of theſe Diſtances, it may be needful to have ſeveral, and thoſe very accurate Obſervations, made by the Skilful, and taken by the help of the beſt Teleſcopes.

Whether Light be propagated in an Inſtant, or in Time?

BY the Eclipſes of *Jupiter*'s *Moons* we are able to give a Solution of a Problem, which is the moſt noble and curious in Natural Philoſophy, which cannot but raiſe our Wonder and Amazement; that is, Whether Light be propagated to us in an Inſtant; or if its Motion be ſucceſſive, and if it takes ſome Time to arrive from the *Sun*, or any diſtant Object to us? Now theſe Eclipſes do ſhew us, that there is no inſtantaneous Motion in Light, though it comes from the Heavens to us with a prodigious quick Motion, and incredible Celerity.

FOR

This Question determined by the Observation of the Eclipses of Jupiter's Moons.

FOR if the Motion of Light were in an Inſtant, when the *Earth* is at T, at his greateſt Diſtance from *Jupiter*, an *Aſtronomer* here would obſerve an Eclipſe of a *Satellit* at the ſame Moment of time he would do, were the *Earth* at X at her neareſt Diſtance to *Jupiter*: For, according to this *Hypotheſis*, Light is propagated in the ſame Inſtant through all Spaces indefinitely, whether near, or never ſo much remote. But if Light takes up any time for its Propagation through Space, it will ſooner paſs through a ſhorter Space than a greater. And therefore an Obſervator at X being nearer to *Jupiter* than one at T, by the Diſtance X T, which is almoſt equal to the Diameter of the *Earth*'s Orbit, will ſooner obſerve the Eclipſe of a *Satellit* than a *Spectator* can do at T. And therefore from the Difference of thoſe Times, which is proportional to X T the Difference of Diſtances, we can collect the Velocity of Light; and ſo this Matter is in Reality. For whenever the *Earth* is at its neareſt Diſtance from *Jupiter*, the Eclipſes are found to happen ſooner than they do when they are obſerved from T at a greater Diſtance, where they fall out ſenſibly later than they ought to be, according to our Aſtronomical Computations. Theſe quicker and ſlower Returns of Eclipſes having been obſerved for many Years by Mr. *Romer* with much Care and Diligence, upon them he founded his Argument for demonſtrating the ſucceſſive Propagation of Light; and by them he proved, That Light, like all other Bodies in Motion, had a determined Degree of Velocity, and took a determined Time to move through a given Space. To which Opinion the moſt Part of the *Aſtronomers* and *Philoſophers* do now give their Aſſent.

THE Particles therefore of Light, though their Minuteneſs be indefinite and not eaſily to be imagined, yet they have a progreſſive Rectilinear Motion, and are not diffuſed as by the Waves of any *Medium* or Fluid. *Romer* determines the Velocity of Light to be ſuch, that it reaches us here from the

Sun

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Sun in the Space of 11 Minutes: But that Diftance does not feem to be lefs than 50000000 Miles; which Space Light paffes thro in fo fmall a time, that fo prodigious a Velocity cannot eafily be conceived by us, which fo much exceeds the Velocity of the fwifteft Bodies we know. For though the *Earth* has a very quick Motion round the *Sun*, yet its Velocity, compared with the Velocity of Light, is no more than that of a Snail, in Comparifon of the Swiftnefs of the *Earth*.

The Longitude of Places determined by the Obfervations of thefe Eclipfes.

FROM the Eclipfes of *Jupiter*'s *Moons*, we have likewife this Advantage, that when they are obferved in different Places of the *Earth*, the Longitude of Places are by fuch Obfervations determined. But that this Method of finding the Longitude may be more eafily underftood, we muft firft lay down fome few Principles.

IF through the *Poles* of the *Earth* and any Place, there be drawn a great Circle upon its Surface, this Circle, by the Rotation of the *Earth*, will be turned round the *Earth*'s *Axis*: And when the Plane of this Circle produced paffes thro' the Body of the *Sun*, all the Inhabitants which live under this Circle, will then obferve the *Sun* to come into their Meridian, and they will have Mid-day; from whence this Circle has the Name of a Meridian, from the *Latin* Word *Meridies*, which fignifies Mid-day. Now if we imagine another Meridian placed more *Weftwardly*, which with the former makes an Angle of 15 Degrees, the Plane of this Meridian will pafs through the *Sun* one Hour later than the former did; and therefore when the Inhabitants under this Meridian reckon Mid-day, the Inhabitants under the firft will reckon one Hour after Mid-day. If there be a Meridian which makes an Angle of 30 Degrees with the firft we mentioned; then when they that live under this Meridian have Mid-day, thofe that live under the firft will reckon two of the Clock after Mid-day; and fo for every 15 Degrees of the Equator which lies between the two Meridians, fo many Hours more do they reckon, who

who live under the more *Eastern* Meridian, than they who live under the *Western*. And after the same manner for every Degree of the Equator between Meridians, the *Eastern* People are four Minutes sooner in their Reckoning than the *Western*; and for every 15 Minutes of a Degree, they reckon one Minute in Time. As for Example, If the Arch of the Equator between the two Meridians consists of 85 Degrees, dividing 85 by 15, the Quotient $5\frac{2}{3}$ shews, that under the more *Easterly* Meridian they reckon the fifth Hour and 40 Minutes, when they under the *Western* Meridian have Mid-day. And when the *Eastern* People have Mid-day, those to the *West* will reckon their Time to be the sixth Hour and 20 Minutes in the Morning; and the Difference between the Hours which are reckon'd under these two Meridians, will always be $5\frac{2}{3}$, if the Arch of the Æquator intercepted between them be 85 Degrees.

ON the contrary, having the Difference of the Hours which are reckon'd under two different Meridians for the same Moment of Time, we shall by this Difference find the Arch of the Equator intercepted between them; which Arch is called the *Difference of Longitude* of the Places under those Meridians, when the Longitudes are computed from one fixed and settled Meridian, which is called the *first Meridian*: And this Arch is found by multiplying the Difference of the Hours by 15, and the Product shews the Degrees. So likewise if the Minutes of Time be multiplied by 15, and the Product, if it exceed 60, be divided by 60, the Quotient and Residue will give the Degrees and Minutes that are further to be added to the former, and which make up the Difference of Longitude of the Places. For Example, Suppose the Difference of the Hours to be 7 and 22 Minutes; 7 multiplied by 15 is 105, and 22 by 15 is 330 Minutes; which divided by 60, gives 5 Degrees 30 Minutes: And therefore the whole Difference of Longitude is 110 Degrees 30 Minutes. These things being noted,

IF

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IF in two different Places the Beginning of an Eclipse of any of *Jupiter*'s *Moons* be observed, and the Times marked when this Beginning happened; according to the Times of the respective Places, the Difference of Hours converted into Degrees and Minutes of the Equator, will shew the Difference of Longitude of those Places.

IF we had *Ephemerides* of the Motions and Eclipses of *Jupiter*'s *Moons*, accurately computed for any Meridian; instead of an Observation in another Place, we might consult the *Ephemerides*, which tell when the Eclipse is to be observed in that Place; and we might take from them the Hours and Minutes when the Eclipse happens in that Place; and this time compared with the Time the Eclipse is observed in any other Place, will give the Difference of Times in those two Places: And from thence we can find out the Difference of their Longitudes, as before. The Longitude of Places may likewise be found by Observations of Eclipses of the *Moon*, or the *Appulses* of the *Moon* to the *fixed Stars*, observed from several Places: But these are Appearances that are more seldom to be observed than are the Eclipses of the *Satellits* of *Jupiter*.

Upon Land the Eclipses are easily observed, and the Longitudes found, but not at Sea.

UPON Land and firm Ground the Eclipses are easily observed; and if they could be as easily observed at Sea, the Art of Navigation would be brought almost to perfection, and liable to no Errors in Computation; but at Sea the Motion and tossings of the Ship renders all Observations of such Eclipses impracticable. And therefore, if any could find a Method for determining the Longitude of a Ship at Sea at any time, he would then oblige the Seamen with a Discovery, by them more desired than any thing else in Navigation; and which would be so useful to the Publick, that the Parliament hath thought fit to allow a large Reward of 20000 Pounds to the Discoverer. Upon which, many, tempted by so great a Reward, have spent much Labour and Thought, for to make the Discovery, but to no purpose: For

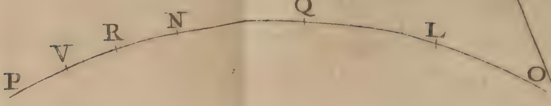
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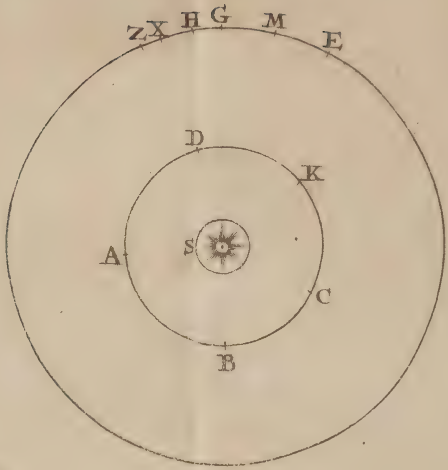
Fig. 1.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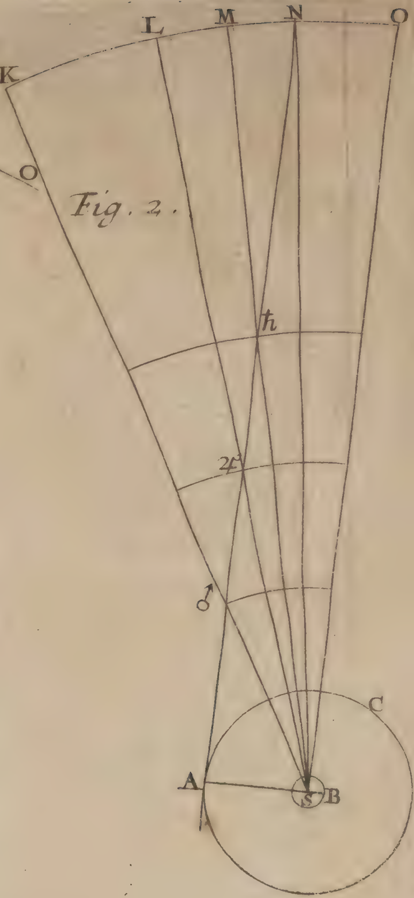
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Fig. 2.
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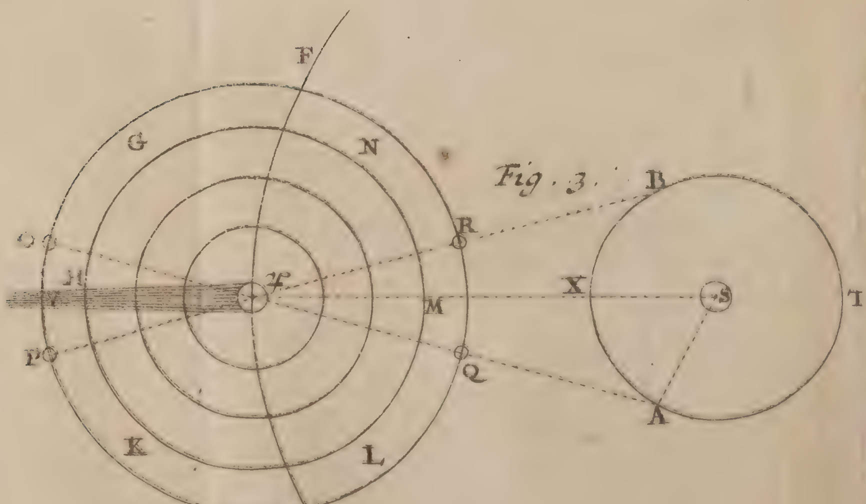
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no Man has hitherto been able to lay hold on the Reward, though they have propoſed many different Methods and Ways of attaining it. Many being much in Love with their own Inventions, imagining that they had certainly found it, have demanded the Reward promiſed to the Diſcoverer; but yet moſt of theſe Men have been ſo ignorant that they have ſcarce known what it is to find the Longitude. Lecture XVII.

LECTURE XVII.

Of COMETS.

BESIDES the ordinary *Planets*, which are always in our Neighbourhood, and within our View, there are another ſort of *Planets* which may be called *Temporary*; which are conſpicuous only for a Seaſon, after which they again withdraw, and are no longer viſible. The ancient Philoſophers allowed them a Place in the heavenly Regions, and ranked them in Stations far above the *Moon*. For *Ariſtotle*, *Seneca*, *Plutarch* and others teſtifie, That the *Pythagoreans*, and the whole *Italian* Sect maintained, that a Comet was a kind of *Planet* or *wandering Star*, which appeared again after a long Interval of time. *Hippocratis Chius* was of the ſame Opinion, as *Ariſtotle* informs us: The ſame was the Opinion of *Democritus*, as we are told by *Seneca* in his *Natural Queſtions, Book* VII. *Chap.* 3. For, ſays he, "*Democritus* the moſt curious "and ſubtile of all the Ancients, ſuſpected, that "there were many more *Stars* which moved, un-"derſtanding by them the Comets; but he neither "eſtabliſhed their Number or their Names, the

Comets are a ſort of Planets.

The Philoſophers Opinion of Comets.

"Courſes

Lecture XVII.

"Courses of the five *Planets* not having as yet "been discovered. Again, *Seneca* assures us, That *Apollonius Myndius*, one of the most skilful Philosophers in the Search of Natural Causes, did assert, That the *Chaldeans* reckon'd Comets among the other *wandring Stars*, and that they knew their Courses. *Apollonius* himself maintained, That a Comet was a *Star* of its own kind, as the *Sun* and *Moon* are, but that its Course was not yet known: That by its Motion it mounts very high in the Heavens, and only appears when it descends into the lower Part of its Orb. And *Seneca* himself imbraces this Opinion: 'I cannot believe, 'says he, that a Comet is a Fire suddenly kindled, 'but that it ought to be ranked among the Eter'nal Works of Nature. A Comet has its proper 'Place, and is not quickly to be moved from 'thence; it goes its Course, and is not extinguish'ed, but runs off from us. But you will say, if 'it were a *wandering Star* it would keep in the Zo'diack: But who can set one Boundary to all the '*Stars*? Who can restrain the Works of the Divi'nity to a narrow Compass? For each of those Bo'dies which you imagine to be the only that have 'Motion, have very different Circles; why there'fore may there not be some that have peculiar 'Ways of their own, wherein they recede far from 'the rest? But that their Courses may be known, 'it is necessary to have a Collection of all the an'tient Observations about Comets; for their Ap'pearances are so rare, that their Orbits are not yet 'determined; nor can we as yet find if they have 'their Periods, and if they return again in a cer'tain Order." At last he thus prophecies. 'The 'time will come wherein these things which are 'now hid from us, will be discovered; which 'Observation, and the Diligence of after-Ages will 'find out; for it is not one Age that is sufficient 'for so great matters. The time will be when Po'sterity will wonder that we were ignorant of things 'so plain: One will arise who will demonstrate in 'what Regions of Space the Comets wander, why they

'they recede ſo far from the other *Planets*, how 'great, and what ſort of Bodies they are. Lecture XVII.

BUT for all this, the whole Sect of *Peripateticks*, fearing that Generations and Corruptions ſhould be introduced into the Heavens by placing the Comets in them, thruſt all the Comets down into the Sublunary Regions, and would maintain, that they were nothing but a kind of Meteors. But the *Phænomena*, or the Manner theſe Comets appear in, will not ſuffer them to have a Place ſo low, and ſo near to us. For it is clear, that they are not generated in our Atmoſphere, becauſe they are certainly far higher than it reaches: For Comets are to be ſeen at the ſame time from different Places of the *Earth*, which are at great Diſtances from one another, which cannot happen to any Body that reſides within our Atmoſphere, which is not extended upwards above Fifty Miles.

The Peripateticks *ſuppoſed Comets to be Meteors generated in the Air.*

BUT that Comets are not only above the Air, but alſo beyond the *Moon* is plain; becauſe Comets ſeen from different Places, are obſerved to be at the ſame Diſtance from a *fixed Star* which is near them. As for Example, the Comet which *Tycho Brahe* obſerved at *Uraniburg*, was likewiſe ſeen by *Hagecius* at *Prague* in *Bohemia* at the ſame time; which two Places differ 6 Degrees in Latitude, and are nearly under the ſame Meridian; and both meaſured the Diſtance of this Comet from the *Star* we call the *Vultur*; that is, how much it was below it towards the Horizon; for both the *Vultur* and it were in the ſame Vertical Circle, and both Obſervators found their Diſtance the ſame, and conſequently they both viewed the Comet in the ſame Point of the Heavens; which could not be, unleſs it had been higher than the *Moon*.

Comets are higher than the Moon.

LET the Circle ABG repreſent the *Earth*, in which let *Uraniburg* be in A, and *Prague* at B: let D be the Place of the Comet: let FCE be the Firmament of the *fixed Stars*, in which let the *Star* F be the *Vultur*; the Place of the Comet ſeen

Plate XVI. Fig. 1.

A Demonſtration that Comets are higher than the Moon.

Lecture XVII. seen from *Uraniburg* among the *Stars* is E, and its Distance from the *Vultur* is the Arch FE; but the Comet seen from *Prague*, appears in C; and its Distance from the *Vultur* is the Arch FC, which is less than the Arch FE. But by Observation it has been found, that this Comet seen from both these Places, seemed to be at the same Distance from the *Vultur*; and therefore the Arches FE and FC are equal, or rather the same. So great therefore is the Distance of the Comet from the *Earth*, that the Arch CE vanisheth, and is altogether imperceptible: But the *Moon* seen from these two Places would appear to have different Distances from the *Vultur*; and so therefore would a Comet, were it as near as she is: This Comet therefore was further distant off than the *Moon*.

The true and the apparent Place of a Comet. A Comet seen from the Center of the *Earth*, would appear in G; but from the Surface of the *Earth* at A it is observed in E: The first is called the *Comet*'s *true Place*, and the second, its *apparent Place*; and the Distance GE between the true and apparent Place, is called the *Parallax* of the Comet: by it a Comet is always depressed more towards the Horizon, than it is in its true Place.

Its Parallax. Now the *Parallax* of any *Star* is always equal to the Arch which measures the Angle, that the *Earth*'s Semidiameter, passing through the place of the Observator, is seen under from the Comet; as we shewed before when we treated of the *Parallax* of the *Moon*.

NOW if there be no sensible *Parallax*, the Angle under which the Semidiameter of the *Earth* is seen from a Comet, will not be sensible; and therefore the Comets must needs be at a vast Distance from us, since the *Earth* seen from thence appears no bigger than a Point.

A Way to find if a Comet has a sensible Parallax. BY the help only of a Thread, in matter of so great Nicety, we may find out if a Comet have any sensible *Parallax*: For a Comet, just before it disappears, goes so slowly, that it scarce seems to move; and it may be twice observed in this manner:

her: First, when it is very high above the *Horizon*, take any two *Stars* between which the Comet lies in a Right Line parallel to the *Horizon*, which, by extending the Thread directly before the *Stars*, may be easily tryed: afterwards when the Comet approaches near to the *Horizon*, by extending the Thread we must again try, if it still keeps in a Right Line between the same two *fixed Stars*. Now if there be any sensible *Parallax* which depresses the Comet, it cannot be seen in the same Right Line as before; and therefore if it keeps the same Position as to those *Stars*, it is a convincing Argument that the Comet has no sensible *Parallax*, and must therefore be at a prodigious Distance from us. We need not here fear any Error arising from Refraction, which always raises the *Stars*, and makes them appear more elevated above the *Horizon* than they are; for this Refraction equally affects both Comet and *Stars*, and therefore it will not change their Positions in respect of one another.

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Another Method for the same.

A Comet may likewise be observed when it is near the *Eastern* Part of the *Horizon*, and in a Right Line with two *Stars* that are both in the same Circle which is perpendicular to the *Horizon*: And afterwards, when the *Stars* rise higher, and are not in the same Vertical Circle as before, if it appear still to be in the same Line with them, it can have no sensible *Parallax*; and therefore its Course must be very high in the Heavens. But if it should be found more depressed than to appear in the Right Line that joins the *Stars*, then the Comet must needs have a *Parallax*. If while these Observations are making, the Comet should have a proper Motion of its own, there must be made an Allowance for that Motion, according to the time between the two Observations.

Comets are affected with the Parallax of the Annual Orb.

AS the want of a Diurnal *Parallax* was an Argument for placing Comets above the *Moon*, so their being subject to the *Parallax* of the Annual Orb is a convincing Proof of their descending

Lecture XVII. into the Planetary Regions; for Comets which have a Motion forward, according to the Order of the Signs, near the time of their disappearing, are all of them either slower than usual, or even Retrograde, if the *Earth* be between the *Sun* and them; or they are quicker than ordinary in their Motions when the *Sun* is between the *Earth* and them; and they appear in *Conjunction* with the *Sun*, as the *Planets* are observed to do. On the contrary, those Comets which have their proper Motions Retrograde, or contrary to the Order of the Signs, are quicker than usual when they begin to withdraw themselves, and disappear when the *Earth* is between the *Sun* and them; or else they slacken their Pace, and seem to move more slowly when the *Earth* is in the opposite Position. These Changes in their Motions arise from the Motion of the *Earth*, and its various Position, as in the *Planets*, who, according as the Motion of the *Earth* agrees with theirs, or is contrary to it, sometimes appear to go with a Retrograde Motion, sometimes they go slower, and sometimes with a quicker Motion.

When a Comet is seen Retrograde.

IF the *Earth* move the same way as the Comet does, and hath an Angular Motion round the *Sun* quicker than it, so that the Right Lines which constantly joins the *Earth* and Comet, all converge to points beyond the Comet; this Comet seen from the *Earth*, upon the account of his slower Motion, will appear Retrograde: But if the Motion of the *Earth* be less than that of the Comet, the Motion of the *Earth* takes off from the visible Motion of the Comet, and then the visible Motion of the Comet seems to be slower. But when the *Earth* and Comet have contrary Motions, the Comet's apparent Motion is thereby accelerated.

WE infer the same thing from the Curvature of a Comet's Way, for they generally seem to move in great Circles almost as long as their Motion is swift. But at last when that part of their apparent Motion which arises from the *Parallax* of the Annual Orb, bears a greater Proportion to their

their whole apparent Motion; then they uſe to deviate from moving in a great Circle; and when the *Earth* moves one way, they go the contrary: This Deflection or Deviation ariſes chiefly from the *Parallax* of the Annual Orb, and exactly anſwers to the Quantity of the *Earth*'s Motion. And by Obſervation it has been found in ſome Comets ſo great, as ſufficiently to prove that they have deſcended far below *Jupiter*: And in their *Perigeons* and *Perihelions*, when they are neareſt to us, they often come within the Orbit of *Mars*, and even the Orbits of the inferiour *Planets*. Lecture XVII.

WHEN the Comets recede from the *Earth*, and approach the *Sun*, their Luſtre and Light is encreaſed, although their apparent Diameters be diminiſhed upon account of their further Diſtance from us.

The Figures of Comets.

THE Figures of Comets are obſerved to be very different; for ſome of them throw forth Beams like Hair every way round them, and theſe are called *Hairy Comets*. Others again have a long Beard, or rather a fiery Tail oppoſite to the Region in which the *Sun* is ſeen; and they are called *Bearded*, or *Comets with Tails*. Their Magnitude has alſo been obſerved to be very different; many of them, without their Hair, appear no bigger than *Stars* of the firſt Magnitude. But ſome Authors have given us an Account of others which were much greater; ſuch was that which appeared in the time of the Emperor *Nero*, which, as *Seneca* relates, was not inferiour in Magnitude to the *Sun* itſelf. So the Comet which in the Year 1652. *Hevelius* obſerved, did not ſeem to be leſs than the *Moon*, though it had not ſo bright a Splendor; for it had a pale and dim Light, and appeared with a diſmal Aſpect. Moſt Comets have a denſe and dark Atmoſphere ſurrounding their Bodies, which weakens and blunts the *Sun*'s Rays that fall upon it; but within it appears the Kernel or ſolid Body of the Comet, which, when the Clouds are diſperſed, gives a ſplendid and briſk Light.

Lecture XVII.

Comets have their Apparent diurnal Motion from East to West.

COMETS, since they are at such a distance from the *Earth*, like all other *Stars*, must have the Apparent Motion round the *Earth* from *East* to *West*, which arises only from the Rotation of the *Earth* round its *Axis*. But besides this they have a real and proper Motion of their own, by which they are continually shifting their place in the Heavens, and have their proper courses in the Celestial Regions. The Antients were not ignorant of such a Motion, for they never had reckoned them among the wandring *Stars*, unless they had known that like the *Planets*, they had their peculiar Courses: *Seneca* acknowledged and observed that they had such a Motion, and said that their way was in a Right Line, or as the *Astronomers* use to say, in a great Circle. For in the Seventh Book of his Natural Questions, Chap. 8. he says, 'that the Course of a Comet is 'easy and quiet, that it takes a determined way: 'That Comets do not proceed in a confused and 'tumultuous manner, as some believe, nor are they 'driven by Turbulent and uncertain Causes. In his 29th Chap. he mentions two Comets, one of which in the space of six Months passed thro' one half of the Heavens: Another in the Time of the Emperor *Claudius*, was first observed towards the *North*, which by Degrees arose directly higher and higher, 'till it quite disappeared.

They have likewise a proper Motion of their own.

The Method of finding the Course of a Comet.

BY the means of a Celestial Globe, in whose Surface the *Stars* are rightly placed and painted, by a Mechanical Method the way of a Comet may be easily traced in the Heavens. Let there be every Day observed four *Stars* which are round the Comet, and let them be such as the Comet may be in the Right Lines which joins the two opposite *Stars*; which may easily be found out by the means of a Thread placed before the Eye, and extended over against the *Stars* and Comet: For Example, let the Comet's place be A, between the four *Stars* B, C, D, E, so that the Line joining the *Stars* B and D may pass thro' the Body of the Comet; and so likewise the Lines passing thro' the

Plate XVI. Fig. 2.

the *Stars* C and E. And therefore upon a Globe in which are marked theſe four *Stars* in their proper places, extend one Thread thro' the *Stars* B and D, and another thro' the *Stars* C, E, and the Interſection of the Threads will give you the place of the Comet. If this be daily done, and the place of the Comet be every Day taken, by this means we ſhall manifeſtly find out the Courſe a Comet takes in the Heavens, which will be found to be a great Circle; for all the Points thus mark'd will be found to fall on the Periphery of a great Circle: And having any two Points of this Circle, we ſhall find its inclination to the Ecliptick, and the places of the *Nodes*; for it is only obſerving where a Thread ſtretched thro' the two Points cuts the Ecliptick.

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Another way of doing the ſame.

THERE is another way of finding out the proper courſe of a Comet, by obſerving every Day its diſtance from two *fixed Stars*, whoſe Longitudes and Latitudes are known; from which diſtances we can compute the places of the Comet; and theſe places being marked on the Surface of a Celeſtial Globe, will manifeſtly ſhew that the Courſe of a Comet is in a Portion of a great Circle, excepting that the Motion of the *Earth* will make it appear to deviate a little from it.

The Courſe of a Comet appears nearly be in a great Circle.

The Motion of Comets is in Planes which paſs thro' the Eye or the Sun.

HENCE it is manifeſt that the Motion of a Comet is in a Plane, which paſſes thro' the Eye of the Spectator, or more exactly which paſſeth thro' the *Sun*, for all viſible Motion that is made in ſuch a Plane, however it be inclined to the Ecliptick, will always appear to be in the Periphery of a great Circle. Moreover, the Motion of a Comet is regular and orderly, and tho' it is unequal, yet there is a certain exact order obſerved in the very inequality of Motion. The proper Motion of Comets is not the ſame in all, but each has its peculiar Courſe: Some go from the *Weſt* to the *Eaſt*, others from *Eaſt* to *Weſt*, contrary to the order of the Signs, and their direction is contrary to the way the *Planets* take, who all move from *Weſt* to *Eaſt*: All of them that

Their Courſes various.

Lecture XVII. exactly obſerved, turn *Southwards* or *Northwards*, with different inclinations to the Ecliptick; and they are not like the *Planets* to be comprehended within the *Zodiack*, but they quickly depart out of it, and with various Motion paſs thro' all the Regions of the Heavens, ſome with a quicker, ſome a ſlower Motion: The greateſt Velocity that any we have yet ſeen has had, was that which was obſerved by *Regiomontanus*, which Comet moved in one Day fully forty Degrees. Some are ſwifteſt in the beginning of their appearance, and ſlacken their pace as they begin to vaniſh. Others again in the beginning and end of their Appearance have ſlow a Motion; but in the middle Time they are carried with a greater Velocity.

Comets deviate from a Courſe in a great Circle. IT his been obſerved that ſome Comets for a few Days before they diſappeared, did not keep their Courſe exactly in a great Circle, but did ſomewhat deviate from it, ſo that the Angle of the Comets Orbit and the Ecliptick, was found to be different at laſt from what it was at firſt: But this deflection was only apparent, and did not ariſe from the real Motion of the Comet, but from that of the *Earth*, as we ſhewed in the Inferiour and Superiour *Planets*; whoſe diſtance and Inclination to the Ecliptick is various, according to the different Poſition of the *Earth*, whereas if they were obſerved from the *Sun*, any one of them would always appear to move in the ſame great Circle.

The true Line that a Comet deſcribes. ALTHO' the Motion of a Comet appears to be in a great Circle, yet its true way may be quite different from a Circle, and may be in very various and different Lines, as either a Right Line, an Elliptick, Parabolick, or Hyperbolick Curve; or it may be any other Curve deſcribed in the ſame Plane: for all Motions in whatever Line the moving Body takes, when it lies in a Plain paſſing thro' the Eye, will always be obſerved to be performed in a great Circle. Many *Philoſophers*, and not a few *Aſtronomers*, have maintained that the

the Comets Motions are Rectilinear; But that which anſwers beſt to their Appearances is a Motion in a Parabolick or Elliptical Orbit. And if their Orbits be Elliptical, they are extreamly excentrick, ſo that their greater *Axis* bears a very conſiderable Proportion to their leſſer; upon which account they differ very much from the *Planets*, which tho' they move in Elliptical Orbits, yet they are ſo little excentrick, that they differ but a ſmall matter from Circles: Now the *Sun* reſides in the common *Focus* of the Orbits of both Comets and *Planets*. And the Comets obſerve the ſame Law in their Circulations round the *Sun* as the *Planets* do, that is, they move at ſuch a rate in their Orbits, that the Line which joins the *Sun* and them, does always deſcribe Areas or Spaces proportional to the Times; And therefore upon the ſame account as the *Planets*, they likewiſe muſt have a Gravity or Propenſion towards the *Sun*.

Lecture XVII.

The Comets when they become viſible, when inviſible.

WHEN the Comets come to the inferiour Parts of their Orbits, and deſcend towards the *Sun*, or are juſt aſcending from him, then only they become viſible; afterwards departing from the *Sun*, and aſcending higher in their Orbits, they run out into far diſtant Regions, and withdraw themſelves from our Sight: for upon the account of their going further off the *Sun*, the Light they receive from him is thereby much weakned; and becauſe likewiſe of their greater diſtance from us, their Apparent Diameters become conſtantly leſs, till at laſt they vaniſh into a Point, and become inviſible. In their *Aphelions* whither they run out into far diſtant Regions, becauſe of the great Excentricity of their Orbits, they have a very ſlow Motion; but in their *Perihelions* where they come near the *Sun*, they move with a quick pace.

LET S be the *Sun*, A P D G the Elliptick Orbit of a Comet; TCE the Orbit of the *Earth*. If we ſhould ſuppoſe the *ſemi-Axis* of the Comet's Orbit to be 100 times greater than the *ſemi-Axis* of the *Earth*'s Orbit, or which is the ſame, than

its mean diſtance from the *Sun*, that Comet would not compleat its Revolution in leſs than 1000 Years; for the Squares of the Periodical Times of the *Earth* and Comet, muſt be as the Cubes of their mean diſtances from the *Sun*: and the Comet becomes viſible only for that part of its Period, wherein it deſcends towards the *Sun*, and approaches near the *Earth* as in F; and then after it hath paſſed its *Perihelion*, conſtantly riſing higher from the *Sun* about G, it will begin to vaniſh, and will not be viſible without a Teleſcope. If the *Aphelion* diſtance be to the *Perihelion*, as 1000 is to one, the Velocity of a Comet in the *Perihelion*, will bear the ſame Proportion to the Velocity at the *Aphelion*. For the Area A S B muſt be but equal to the Area P S D, if the Arches AB and P D be deſcribed by the Comet in equal times, and then the Arch P D muſt be greater than A B, in the ſame Proportion as A S is greater than P S. This is the Proportion of their abſolute Velocities. But their Angular Velocities about the *Sun* are in a duplicat Proportion of theſe diſtances, or as 1000000 to 1, ſo that while the Comet in its *Perihelion* deſcribes one Degree with its Angular Motion; when it aſcends to its *Aphelion*, it will deſcribe in an equal Time but the $\frac{1}{1000000}$ of a Degree; ſo that there it may have ſo ſlow a Motion, that it will require ſeveral Years before it can compleat a Degree of Angular Motion.

Plate XVI. Fig. 3.

The ſmall Portion of the Ellipſe which a Cone deſcribes while it is ſeen by us, may be eſteemed as a Parabola.

SINCE the Elliptick Orbits of Comets are all of them very Excentrick, thoſe Portions of them wherein they become viſible to us, may paſs for Parabola's. For if one of the *Focus*'s of an Ellipſe recede infinitely from the other, this Ellipſe will thereby be changed into a Parabola, as when the two *Foci* come together and coincide, the Ellipſis is changed into a Circle. Now by conſidering that Portion of a Comet's Orbit which is near the *Perihelion*, as a peice of a Parabola near its *Vertex*, the Calculation of their Motions becomes much eaſier; and upon that *Hypotheſis* our moſt Skillful *Aſtronomer* and *Geometer* Dr. *Halley*, has

conſtructed

conſtructed and Calculated a Table, by which the Motions of all Comets are eaſily computed, and the Calculations founded on this *Hypotheſis*, do exactly agree with the Obſervations made on them. Dr. *Halley* himſelf having computed the Motions of ſeveral Comets, and compared them with Obſervations made by others, has found there was ſo nice a Correſpondence between them, that the Calculation ſcarce ever differed from the Obſervation above three Minutes. By which Examples it is abundantly manifeſt that this Theory ſatisfies all the Appearances and Motions of Comets, with no leſs exactneſs than the Motions of the *Planets* are accounted for, and foretold from the Theories we have of them, whoſe computed places do ſometimes differ from Obſervations as much as in Comets. And altho' the Motions of Comets are much more unequal than thoſe of the *Planets*, yet this Theory does wonderfully anſwer all their Appearances: and therefore ſince it is built upon the ſame Laws as the Theory of the *Planets*, and the Motions of one governed by the ſame Phyſical Cauſes as they of the other are; and ſince it accurately anſwers all Obſervations of *Aſtronomers*, it cannot but be the true Theory. Lecture XVII.

Many Comets move from East *to* West.

ALTHO' all the *Planets* have their proper Motions from *Weſt* to *Eaſt*, yet many Comets have been obſerved to hold on in a contrary Courſe, and have been ſeen to go from *Eaſt* to *Weſt*, with a very great Degree of Velocity. Such was the Courſe of the Comet which *Regiomontanus* obſerved in the Year 1472, that deſcribed 40 Degrees of a great Circle in one Day. Hence we can poſitively conclude that there are no *Vortices*, or Whirle-pools of Fluid matter in the Heavens, which according to the Opinion of ſome *Philoſophers* carry the *Planets* round the *Sun*: for if there were any ſuch Whirle-pools, when the Comets come down and enter within the Region of the *Planets*, they muſt be neceſſarily driven out of their Courſe, by the rapid Motion of the Solar Vortex, as by a mighty Torrent, which near the

Therefore there can be no Vortices.

Lecture XVII.

Earth is of ſuch a force, that it carries it above 20000 Miles in an Hour: and who can think that ſo rapid a Stream would not affect the Comets, and when they have a Motion contrary to its Motion, ſoon deſtroy it: For what can reſiſt ſo violent a Torrent of Fluid matter. Now many Comets have been obſerved who take a Courſe directly contrary to this Stream, and which perform their Motions with the greateſt Freedom and without the leaſt Reſiſtance, juſt after the ſame manner as they would do in a void Space, where there is nothing to withſtand them. But this is plainly repugnant to the Nature of a *Vortex*, for that *Medium* which can put the *Planets* in motion, would without all Queſtion, ſet all other Bodies which Swim in it a going the ſame way. But ſince there is nothing like this obſerved in Comets, we muſt acknowledge that in the Heavens there is no Reſiſtance, and therefore no *Medium* or Fluid, which compared with our Air hath any ſenſible denſity; For our Air gives a very conſiderable Reſiſtance to all Bodies that move in it.

There is no Fluid in the Heavens which has a ſenſible Denſity.

LET not therefore the *Carteſians* and *Leibnitians*, talk to us any more about their *Vortices*; for the Appearances of the Celeſtial Bodies are ſuch, as that we can by no means admit of them; ſo that they who labour to explain the Motions of the Heavens by them, do only amuſe us with trifles and impoſſibilities; and it is to no purpoſe to trouble our ſelves any longer with their Fancies, ſince there is Demonſtration againſt them.

SINCE the Reſiſtance of a *Fluid Medium* ariſes chiefly from its Denſity, it from thence neceſſarily follows that where there is no ſenſible Reſiſtance of the *Medium*, there the *Medium* muſt have no ſenſible Denſity; and therefore ſince in the Heavens the Comets ſuffer no ſenſible Reſiſtance, but exert their Motions with the greateſt freedom, as if they were in a perfect void or *Vacuum*, there likewiſe the Denſity of the *Medium* muſt be the leaſt that can be, or next to Nothing. And who knows but the *Medium* in the Heavens may be ſo rare

and

and fine, that if you except the *Planets* and their *Atmospheres*, the matter which is diffused thro' all the rest of the Planetary Region, or our Solar System, may not be so much as that which is contained in an Inch of our common Air. For this we have demonstrated to be possible in our Physical Lectures.

Lecture XVII.

A Vacuum or Void is proved.

THE *Philosophers* after this need trouble us no longer with their Metaphysical Quirks against a *Vacuum*; for they seem to be very like the Quibles of the Antient *Sophists* against the possibility of Motion: and as *Diogenes* confuted those *Sophists* by rising and walking, so we may answer the *Cartesians* by bidding them look up into the Heavens, and there notwithstanding their nice and subtle Arguments, they will find, from the Appearances and Motions there observed, a manifest Demonstration for the necessity of a *Vacuum*.

The Tails of Comets.

FEW Comets have been observed before their descent to the *Sun*, and their Return from their *Perihelion*. For before they have been considerably heated in the Neighbourhood of the *Sun*, they scarcely project a Tail to make them remarkable. But after they have been well heated in their *Perihelion*, then they generally send forth a large shining and fiery Tail, which seems to consist of a very fine, rare and luminous matter, which is attenuated by the great heat of the *Sun*, and projected with an immence force from the Body of the Comet. The cause of this Projection perhaps may be very like that whereby a great quantity of fine Lucid Vapour was lately thrown out from the *Earth*, to an immense height above the Air, so that it was visible thro' the greatest part of *Europe*; and in Figure and Lustre looked very like the Tails of Comets, but the matter being spent it soon vanished.

The Tails of Comets always opposite to the Sun.

IT is very remarkable that all Comets have their Tails in opposition to the *Sun*, that is if the *Sun* be in the *West*, the Tail is projected *Eastward*, or if the *Sun* be in the *East*, the Tail looks *Westward*; at Midnight the direction of the Tail is to

the

Lecture XVII. the *North*. Theſe Tails grow bigger as they deſcend to the *Sun*, and at the *Perihelions* they are biggeſt; and as they go further off from the *Sun*, and cool by degrees, the Tail leſſens, till at laſt it is contracted within the Comets Atmoſphere.

COMETS which have ſhort Tails do not throw forth the matter of them with a very quick Motion, in a continual Stream from their Bodies, for then they would ſoon be diſſipated and vaniſh; but theſe Tails ſeem to be rather permanent and fixed Columns of Vapour and Exhalations, which being propagated from the Body with a ſlow Motion upwards, and retaining ſtill the Motion which they had impreſſed in them to go along with the Comet, they ſtill continue to move on with the Body thro' the Celeſtial Regions. From hence we may likewiſe conclude that in the Heavens there is no Reſiſtance; for in them not only the Solid Bodies of *Planets* move, but alſo the thin and fine Vapours which ariſe from Comets feel no reſiſtance, but move with the greateſt freedom, and for a long time preſerve their Motions.

THE great Comet which appeared in the Year 1680, after its departure from the *Perihelion*, projected ſuch a Tail as extended its ſelf more than 40 Degrees in the Heavens; nor can this be a wonder, for it was ſo near the *Sun*, that its diſtance from his Surface at the *Perihelion*, was but a ſixth Part of the Diameter of the *Sun*'s Body; and therefore the *Sun* ſeen from the Body of the Comet would appear to fill the greateſt part of the Heaven, and its Apparent Diameter would not be leſs than 120 Degrees; and therefore the heat it received from thence muſt be prodigiouſly intenſe beyond imagination, for it exceeded above 3000 times the Heat of red hot Iron. And therefore we muſt allow that the Bodies of Comets which can bear ſo great a heat muſt be very denſe, hard and durable Bodies: for if they were nothing but Vapours and Exhalations raiſed from the *Earth* and *Planets*, as ſome have dreamt, this

Comet

Comet, at ſo near an approach to the *Sun*, muſt have been quite deſtroyed and diſſipated. Lecture XVIII.

LECTURE XVIII.

The Spherical Doctrine, or of the Circles of the Sphere.

The Eye of a Spectator is always in the Center of his own View.

SINCE every Spectator in whatever place of the vaſt Expanſion of the Univerſe he reſides, is always in the Center of his own view, when he looks up at the Heavens, he will ſee it as a Concave Spherical Surface, whoſe Center is the Eye, which Surface is every where beſpangled with an innumerable multitude of ſhining *Stars*: and the Spectator will likewiſe obſerve that all the Heavenly Bodies perform their Motions whither real or apparent in this Surface. Now ſince the diſtance of the *Earth* from the *Sun* is but a Point, as it were, in compariſon of the immenſe diſtance of the *Starry* Firmament, in whatever Point of its Orbit the *Earth* is placed, there will be the ſame proſpect of the Heavens, the ſame Poſition and Magnitude of the *Stars* and Figures of the Conſtellations, as a Spectator would obſerve did he reſide in the *Sun*, and therefore it is the ſame thing as to theſe Appearances whither the Center of the Univerſe or Heavens, be placed in the *Sun* or *Earth*: and if we imagine ſeveral Circles to paſs thro' the *Earth*, and to have its Center for theirs, and others Parallel to them to paſs thro' the *Sun*, the Circles in the Heavens will ſeem to coincide, becauſe their diſtance will vaniſh in reſpect of the immenſe diſtance of the *fixed Stars*; and thoſe Circles which are drawn thro' the *Sun* and *Earth* on

It is no matter whither the Center of the Heavens be conſidered to be in the Sun *or* Earth.

Parallel

Lecture XVIII. Parallel Planes will appear to paſs thro' the ſame *Stars* in the Heavens.

A great Circle. FOR the better determining the places of all ſort of *Stars* and obſerving of their Motions, it is requiſite to imagine ſeveral Circles deſcribed in the Heavens, ſome of which are great Circles, others of a leſs ſize. A great Circle is the greateſt that can be deſcribed on the Surface of the Sphere, and divides it into two equal portions, and has likewiſe the ſame Center that the Sphere has, and therefore all great Circles having the ſame Center muſt cut each other into equal Portions or Semicircles.

The leſſer Circles. THE leſſer Circles divide the Sphere into unequal Portions, and have not the ſame Center that the Sphere has; and they take their Denomination from ſome great Circle to whom they are Parallel, as the Equator, Horizon, or Eclip-tick.

The Poles *of Circles.* EVERY Circle of the Sphere hath two *Poles*, which are Points on the Surface of the Sphere, which are at equal diſtances from all the Points of the Circle; and they are placed in the Surface where a Line from the Center perpendicular to the Plane of the Circle meets with the Surface of the Sphere, when the Line is produced both ways.

Circles moveable and immoveable. SOME Circles of the Sphere depend only upon the place of the Spectator, and have a regard to his poſition; others again are produced by Motion: the firſt are called moveable Circles, becauſe as the place of the Spectator is changed ſo are they, and move along with him. The ſecond are called immoveable, and are ſuppoſed to be fixed to the ſame Points of the Heavens.

THE Circles which owe their Origin to Motion, are chiefly the Ecliptick and Equinoctial and their Parallels. For becauſe the *Earth* is carried round the *Sun* in a Year, a Spectator in the *Sun* will ſee the *Earth* deſcribe a great Circle in the Heavens or *Starry* Firmament, which we call the Ecliptick; and it is the very ſame Circle which we in the *Earth*

Earth observe the *Sun* to move in by an Apparent Motion, likewise in the space of a Year, as we shewed before: The Ecliptick is divided into Twelve equal parts, which are called the Twelve Houses or Signs, and they have their Names from the Neighbouring Constellations: they begin at the Vernal Intersection of the Equator and Ecliptick, and are reckoned from the *West Eastwards* as the *Sun* seems to move. The first three Signs are ♈ ♉ ♊, which rise from the Æquinoctial, and ascend *Northwards* to the Point of the Summer Solstice. The next three are ♋ ♌ ♍, which begin from *Cancer* and descend again towards the Equinoctial till they come to the Autumnal Intersection. The third Ternary of Signs consists of ♎ ♏ ♐, which begin at *Libra*, and departing from the Equinoctial *Southward*, reach the Winter Solstice. ♑ ♒ ♓ make the fourth, which begin at *Capricorn*, and end in the Vernal Equinox. Each Sign is divided into 30 Degrees and consequently the whole Ecliptick into 360. The *Sun* is always observed in this Circle and never deviates in the least from it, as the *Planets* do, which go sometimes on one side of it, sometimes on the other, thro' a space of about eight Degrees, and therefore if we imagine a broad Circle or Zone, of about Sixteen Degrees in breadth, which the Ecliptick cuts in the middle, this will be the Space wherein the *Planets* perform all their Motions, and by the *Greeks* it is called the *Zodiack*, by the *Latines Signifer*, or the Sign bearer, because of the Signs placed within it.

Lecture XVIII.

The Ecliptick and its parts.

The Zodiack.

IF we imagine an indefinite number of great Circles to be drawn thro' the *Poles* of the Ecliptick and intersecting of it, these Circles are called Secundaries of the Ecliptick; for by them every *Star* and Point of the Heavens are reduced to the Ecliptick, and have their places in regard to it determined in the Heavens. For the Place of any *Star* reduced to the Ecliptick is that Point where the Secundary passing thro' the *Star* intersects the Ecliptick: The Arch between this Point and the beginning of ♈ or the Vernal intersection, and counted

Secundaries of the Ecliptick.

East-

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Eastward is called the Longitude of that *Star*, as the Arch of the Secundary between the *Star* and the Ecliptick is called the Latitude of that *Star*; and is either *North* or *South*; for the Ecliptick divides the *Starry* Firmament into two *Hemispheres* *North* and *South*.

The Longitude of a Star.

SINCE the *Earth* turns round its own *Axis*, from thence it comes, that the Inhabitants thereof see the Heavens and all the *Stars* revolve round the *Earth* in the Space of twenty four Hours from *East* to *West*; which Apparent Motion is called the Diurnal, or daily Revolution of the Heavens, and was conceived to be by the Force of a moving Sphere called the *Primum Mobile* or first mover, which carried the whole Heavens round with it about an *Axis* which coincides with the *Axis* of the *Earth* produced, as if the *Earth* it self had no Motion, but the Heavens were Volvible. The great Circle which is exactly between the two *Poles* of the *Earth*, or at equal distance from both, is called the *Earth*'s Equator; and if we imagine the Plane of this Circle extended or produced to the Heavens, it will there make the Celestial Equinoctial Circle, or the Equator in the Heavens; and all the *Stars* and every Point of the Heavens, except the two *Poles*, will seem to describe by their Apparent Revolution either this Circle, or a lesser Parallel to it; which Circles are either bigger or lesser, according as the *Stars* which seem to describe them, are more removed or nearer to the *Poles*.

The Primum mobile.

The Equinoctial.

THE Equinoctial and Ecliptick being both great Circles, will cut each other into Semi-circles, and their common intersection will always keep Parallel to its self, and will constantly be directed to the same Point of the Heavens, for we here abstract and consider as nothing, that very small Motion whereby the *Axis* of the *Earth* falls backward, and this Intersection equally with it. And therefore whenever the *Sun* is observed in the Point of the Ecliptick where this intersection is, that is, when the *Earth* is really in the opposite, the *Sun* then by his Apparent diurnal Motion will de-

scribe

ſcribe the Equinoctial Circle in the Heavens; and there being two Points of Interſection, the *Sun* will be obſerved to revolve in the Equinoctial twice every Year, that is, when he is in the two Interſections, Vernal and Autumnal, at which times all the Inhabitants of the *Earth* will have their Days and Nights equal; upon which account this Circle has got the Name of the Equinoctial. The Angle which the Ecliptick and the Equator make at the Points of Interſection is about $23\frac{1}{2}$ Degrees. The *Sun* leaving theſe Interſections by an Apparent Motion, declines every Day from the Equinoctial Circle more and more towards the *North* or *South*, till he comes to the Nintieth Degree from the Interſections, where he appears to be $23\frac{1}{2}$ Degrees diſtant from the Equinoctial, which is his greateſt Declination: For from thence he begins to return again towards the Equinoctial, and therefore the two leſſer Circles, which the *Sun* at his greateſt Declination ſeems by his Diurnal Motion to deſcribe, are called the *Tropicks*, from a Greek Word which ſignifies to return: This upon the *North* ſide of the Equinoctial is called the *Tropick* of *Cancer*, the other on the *South* ſide the *Tropick* of *Capricorn*. How this Apparent Motion of the *Sun* and conſtant change of his Declination ariſe from the real Motion of the *Earth*, the *Sun* himſelf being all the while at reſt, we have already explained in our ſeventh *Lecture*.

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The two Tropicks.

THERE are two remarkable leſſer Circles of the Sphere which are Parallel to the Equinoctial, and theſe are deſcribed by the Apparent Diurnal Motions of the two *Poles* of the Ecliptick round the *Poles* of the Equinoctial, from which they are diſtant $23\frac{1}{2}$ Degrees. They are called the two Polar Circles; this in the *Northern* Sphere is named the *Arctick* Circle, from the two *Bears* which lye near it; the other Circle on the *South* is called the *Antarctick*, or Circle oppoſite to the *Arctick*.

The two Polar Circles

IF thro' the *Poles* of the World, or of the Equinoctial, there be conceived innumerable great Circles to be drawn, they are called Secon-

Secondaries of the Equinoctial.

Lecture XVIII. daries of the Equinoctial, by the help of which the Pofition of every Point of the Heavens, in regard to the Equinoctial, is determined, as before they were determined by the Secondaries of the Ecliptick in regard to the Ecliptick: And the right Afcenfion of a *Star* or Point in the Heavens is an Arch of the Equinoctial, between the beginning of *Aries* and the Point where the Secondary paffing thro' the *Star* cuts the Equinoctial. The Declination of a *Star* or Point is the Arch of the Secondary intercepted between the *Star* and the Equinoctial, which is likewife as the Latitude either *North* or *South*, as the *Star* declines towards the *North* or *South Pole*: From hence thefe Secondaries are called Circles of Declination. And the two chief of them are the two Colures, one of which paffing thro' the two Equinoctial Interfections is called the Equinoctial Colure; and the other, which cuts the former at right Angles and paffes thro' the *Poles* of the Ecliptick, is called the Solftitial Colure, becaufe it interfects the Ecliptick in the Points which are at the greateft diftance from the Equator; to which when the *Sun* comes, he does not fenfibly for fome Days change his Declination, but feems to ftand without approaching to, or receding from the Equinoctial, and therefore thefe Points are called Solftices.

The Right Afcenfion of a Star.

The two Colures.

THAT Circle which is on the Surface of the *Earth* exactly in the middle between the two *Poles* is the *Earth*'s Equator, and by the production of it we fhewed that the Celeftial Equinoctial was formed. And as the places of all the *Stars* in the Heavens are determined by their Longitude and Latitude in regard to the Ecliptick and its Secondaries; fo by the Terreftial Equator and its Secondaries drawn thro' the *Poles* of the *Earth*, the Pofition of Cities and Places upon the Surface of the *Earth* are determined according to Longitude and Latitude. A Secondary of the Equator paffing thro' any place on the *Earth*'s Surface is called the Meridian of that place; becaufe, that when by the Rotation of the *Earth* round its *Axis* the Plane of

The Longitudes and Latitudes of Places.

of that Meridian comes to pass thro' the *Sun*, then the Inhabitants under this Meridian have Midday. The Longitude of any City or Place is an Arch of the Equator intercepted between a certain Point where some fixed Meridian passes, which is called the first Meridian, and the Meridian of the Place. The Antient *Geographers* made the first Meridian pass thro' some known place which was as far *Westward* as they knew, and from thence they reckoned the Longitude of all places constantly *Eastward*: But since by Navigation it has been discovered, that there is no place in the *Earth* that can be esteemed the most *Westerly*, so that there is not another more *Westward* beyond it, this way of computing the Longitude from a first Meridian hath been generally layed aside, and now each *Geographer* determines the Longitudes of places in regard to the Longitude of the chief City of the Country where he dwells. The Latitude of a Place is an Arch of the Meridian of that place intercepted between the Place and the Equator, and is either *North* or *South*, as the place lyes on the *North* or *South* side of the Equator.

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OF the Inhabitants of the *Earth* compared with one another, in regard to their Meridians and Parallels, some are called *Periœci*, that live under the same Parallel, but in the opposite Semicircles of the same Meridian; both of them have the Seasons of the Year the same, the *Sun* by its Annual Apparent Motion coming to or receding from the Vertex of both Places at the same time of the Year; but they change their turns of Night and Day, so that when it is Midday to the one, it is Midnight to the other. Others again are called *Antœci*, whose Habitations lye in the same Semicircle of the Meridian, but in opposite Parallels, and both of them have Midday and Midnight at the same instant of time; but the Seasons of the Year are different, it being Summer to one when it is Winter to the other. Lastly, there are the *Antipodes*, whose Habitations being situated in both opposite Parallels and opposite Meridians, have their Feet

The Periœci.

The Antœci.

The Antipodes.

Lecture XVIII. directly oppofite to one another in a Line paffing thro' the Center of the *Earth*; and they have not only their Days and Nights directly contrary, but alfo the Seafons of the Year: When it is Summer in the one, it is Winter in the other place, and when Midday in the firft, the fecond reckons Midnight.

The five Zones.

THE four leffer Circles in the Surface of the *Earth*'s Globe, which lye directly under the Circles of the fame name in the Heavens, *viz*, the two *Tropicks* and *Polars*, divide the *Earth* into five Portions which are called *Zones*; of which the Torrid is that which is bounded on each fide by a *Tropick*, and was believed by the Antients to be not Habitable by reafon of the violent Heats: But our Modern Travellers and Voyagers have difcover'd this Tract of the *Earth*'s Surface to be the moft fruitful and delightful of all, abounding not only with the things that are neceffary, but fuch likewife as conduce to the fatisfaction and pleafure of Life; upon which account it is very well ftored with Inhabitants. There are two cold *Zones* which the Polar Circles comprehend; in the middle of the one lyes the *Arctick Pole*, of the other the *Antarctick*, and in them the cold is fo exceffive that they are fcarcely habitable. Befides thefe, between the Frigid and the Torrid *Zone*, on each hand lye the two Temperate ones, that on the *North* is poffeffed by us, the other our *Antipodes* keep. *Virgil* elegantly defcribes thefe five *Zones*.

Quinq; tenent Cælum Zonæ, *quarum una corufco*
Semper Sole rubens & Torrida femper ab igne;
Quam circum extremæ dextra lævaq; trahuntur,
Cærulea glacie concertæ atq; imbribus atris.
Has inter mediamq; duæ mortalibus ægris
Munere conceffæ Divûm.

The Amphifcij.

THE Inhabitants of the Torrid *Zone* are called *Amphifcii*, having their Meridian Shadows at different times of the Year projected towards both *Poles*; but when the *Sun* comes to be Vertical to them,

then

then they have no ſhadow, and are *Aſcii* or Shadowleſs, nothing that ſtands perpendicularly upwards having a Shadow at Noon. We who live in the Temperate *Zones* may be named *Hetroceii*, having our Meridian ſhadow projected only towards one *Pole* thro'out the whole Year. But the miſerable People of the two Frigid *Zones* are called *Periſcii*, becauſe the *Sun* not ſetting upon them, their Shadow turns quite round in the Space of twenty four Hours.

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The Aſcii.

The Periſcii.

THE two Circles which we conceive to be immoveable, and determined by their reſpect to the Spectator, are the *Horizon* and Meridian. The *Horizon* is that great Circle which any one when he is placed in a large extended Plane, or in the open Sea obſerves, terminating or bounding his Sight every where round him, by which the viſible Heaven is diſtinguiſhed and ſeparated from the inviſible. This *Horizon* being diſcovered by our Senſes is called the ſenſible *Horizon*, from which the Rational *Horizon* Parallel to it is diſtant by the Semidiameter of the *Earth*, through whoſe Center it paſſes: For the *Aſtronomers* reduce the Appearances of the Heavens to a Spherical Surface, which is not concentrical to the Eye but to the *Earth*.

The Horizon *ſenſible and Rational.*

'TIS true, theſe two *Horizons*, produced to the *fixed Stars*, will appear to coincide into one, ſince the *Earth* compared to the Sphere in which the *fixed Stars* appear is but a Point; and therefore the two Circles which are but a Point diſtant from each other, may be well conſidered as coinciding into one. There are two *Poles* of the *Horizon*, the one is the Point of the Heavens which is directly over the Head of the Spectator, and is called the *Zenith*; the other directly oppoſite under his Feet is named the *Nadir*; and innumerable Circles drawn thro' theſe *Poles* to the *Horizon* are ſtiled *Vertical Circles* or *Azimuths*. Among them there are two particularly remarkable, one of which is the Meridian, and the other is the *Prime Vertical*; the firſt paſſes thro' the *Poles* of the E-

Zenith *and* Nadir, *the* Poles *of the* Horizon.

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quator and the *Zenith*, and cuts the *Horizon* in the Points of *North* and *South*; the other passing thro' the *Zenith* cuts the former at right Angles, and marks upon the *Horizon* the Points of *East* and *West*. These Circles divide the *Horizon*, at their Intersections with it, into four Quarters, each of which is again subdivided into eight Parts, and consequently the whole *Horizon* is divided into Thirty two Parts, which are called the *Rhumbs* or Points of the Compass.

The Vertical *or* Azimuth *Circles.*

The Altitude or Depression of a Star.

THE Altitude or Depression of any *Star*, is an Arch of the Vertical intercepted between the *Horizon* and the *Star*.

AGAIN, the *Azimuth* of a *Star* is an Arch of the *Horizon*, intercepted between the Points of *North* and *South* and the Point where the Vertical passing thro' the *Star* cuts the *Horizon*, and is either *Easterly* or *Westerly*. The rising or setting Amplitude of a *Star* is an Arch of the *Horizon* intercepted between the points where the *Star* riseth or setteth and the points of *East* and *West*; and this Amplitude is either *North* or *South*, according as the *Star* at rising or setting is to the *North* or *South* of those Points.

The Amplitude.

AS in the *Horizon* all the *Stars* first appear and disappear, so in the Meridian Circle they all arise to their greatest height or Altitude, where they are said to *Culminate*: so likewise they are at their greatest depression below the *Horizon* when they arrive at the same Meridian. Now since the Meridian makes Right Angles both with the Equator and *Horizon*, it will divide the Segments of the Equator and all its Parallels, as well those that lye above the *Horizon* as those which are below it, into equal Portions; and therefore the time between the rising of a *Star* and its Culmination or arrival at the Meridian, will be equal to the time between this Culmination and its setting; and because the *Sun* every Day describes some Parallel by its apparent Diurnal Motion, when the *Sun* comes to the Meridian at any time it will be then Midday, and Midnight when he arrives at the same Meridian below the *Horizon*, and from thence this Circle has its Name. The

The Culmination.

Nintieth

Nintieth or *Nonagesimal Degree* is that Point of the Ecliptick which is 90 Degrees distant from the Intersections of the *Horizon* and Ecliptick, and the Altitude of this Point is the measure of the Angle of the *Horizon* and Ecliptick. The *Medium Cæli* or Midhaven, is that Point of the Ecliptick which culminates, or is in the Meridian. In the Ascending Signs from ♑ to ♋, the *Nonagesimal* Degree is to the *East* of the Meridian, but in the Descending Signs from ♋ to ♑, the *Nonagesimal* lyes *Westward* of the Meridian.

The Horizon *and Meridian truly moveable Circles.*

ALTHO' we have here considered the *Horizon* and Meridian as immoveable Circles, taking the Apparent Motion of the Heavens as real; yet if we speak according to truth and the nature of things, the *Horizon* and Meridian are the only moveable Circles, and the *Sun* or a *Star* rises not when it ascends, but when the Plane of the *Horizon* descends below it, so that the *Star* or *Sun* becomes visible. So likewise the *Stars* set not by their own Motion or going down under the *Horizon*, but by the *Horizon*'s ascending and getting above them; which Motion of the *Horizon* ariseth from the Rotation of the *Earth*. So also the *Sun* or *Stars* arrive at the Meridian when the Plane of the Meridian of any place, having an Angular Motion round the *Axis* of the *Earth*, comes to pass thro' the Bodies of the *Sun* or *Stars*.

The Universal Meridian.

SINCE every Meridian finishes its circulation round the *Axis*, or 360 Degrees in Twenty four Hours, it must each Hour have an Angular Motion of 15 Degrees, which is the Twenty fourth Part of 360; and therefore if we conceive a Circle passing thro' the *Poles*, which makes an Angle of 15 Degrees with the Universal Meridian passing thro' the *Sun*, when by the *Earth*'s Rotation the Plane of the Meridian of any Place comes to the Plane of this Circle after it has passed the Universal Meridian, then the Inhabitants in that Meridian will reckon one Hour after Midday, and therefore that Circle is called the Circle of the first Hour. In like manner, if another Circle be conceived cutting the Equinoctial in the Thirtieth

Lecture XVIII. Degree from the Universal Meridian, this will be the Circle of the second Hour; and when the Plane of the Meridian of the Place comes to coincide with it, it will be in that Place two of the Clock in the Afternoon. After the same manner, if thro' the *Poles* and every 15 Degrees of the Equator we conceive Circles to pass, they are called *Horary* Circles, and they will divide the Equinoctial into Twenty four equal parts, and each of them in its order will determine the Hour that is to be reckoned in a Place, when the Plane of the Meridian of that Place comes to coincide with that Circle. So for Example, when the Meridian of the Place comes to the Circle which makes 75 Degrees with the Universal Meridian, the Hour then counted in that place will be the fifth from Noon. But when the Meridian of the Place makes an Angle of 90 Degrees with the Meridian passing thro' the *Sun*, then it will be the sixth Hour. But on the other hand, if we should imagine the Meridian of the Place to be immoveable, and that a Circle passing thro' the *Poles* and the *Sun* should together with the *Sun* turn round the *Axis*, as it appears to do; when the Plane of this Circle in which the *Sun* resides coincides with a Circle that makes an Angle of 15 Degrees with the Meridian of the Place *Westward*, it is then the first Hour after Midday; and the Circle with which the Circle passing thro' the *Sun* and *Poles* does then coincide, is called the Circle of the first Hour: The next Circle to this, which makes an Angle of 30 Degrees with the Meridian of the Place, is the *Horary* Circle for Two of the Clock, and that which makes an Angle of 45 Degrees with the Meridian of the Place, is the *Horary* Circle for Three of the Clock &c.

The Horary Circles.

Plate XVI. Fig. 4.

IN any Place of the Terraqueous Globe the Height of the *Pole* above the *Horizon* is equal to the Latitude of the Place. Let the Circle H Z Q be the Meridian, H O the *Horizon*, ÆCQ the Equator, Z the *Zenith*, and P the *Pole*: the Elevation

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Elevation of the *Pole*, or its Diſtance from the *Horizon*, is the Arch P O, the Latitude of the Place or its diſtance from the Equator is Z Æ. And becauſe the Arch P Æ between the *Pole* and the Equator is a Quadrant, or fourth Part of a Circle, and the Arch Z O from the *Zenith* to the *Horizon* is likewiſe a Quadrant, theſe two Arches ZÆ and P O muſt be equal. Take away the Arch Z P which is common to both, and there will remain the Arch ZÆ equal to the Arch P O, that is, the Latitude of the Place is equal to the Altitude or height of the *Pole* above the *Horizon*.

The height of the Pole *above the* Horizon *is always equal to the Latitude of the Place.*

HENCE we have a Method of meaſuring the Circumference of the whole *Earth*, and of knowing how many Miles it is round the *Earth*: For if we go directly *Northward* till the *Pole* be Elevated one Degree higher, and then if we meaſure the length of the way we have gone *Northward*, and have the number of Miles it contains, we ſhall have the number of Miles in a Degree of a great Circle of the *Earth*'s Globe; and this number multiplied by 360, the Degrees in the whole Periphery, it will give the length of the Circumference of the *Earth* in Miles. By the moſt accurate Obſervations, the Length of a Degree is found to be 69 Engliſh Miles, which was commonly reputed to be only 60 Miles.

LEC-

LECTURE XIX.

Of the Doctrine of the Sphere.

The Right Position *of the* Sphere.

THE Angle contained between the Equator and the Horizon, is measur'd by the Arch of the Meridian Æ H, which is the Complement of the Latitude to a Quadrant. And therefore if that Angle be right, the Latitude of the place will be nothing, or the place will be in the Equator; or the Equinoctial Circle will pass thro' the Vertex of the place, and all the Parallels of the Equator will be perpendicular to the Horizon; And therefore this Position of the *Sphere* is call'd a *Right Position,* in which all these Parallels are cut by the *Horizon* into equal Portions, whence the Stars are as long above the *Horizon* as they lye hid under it: Here likewise the Poles lye in the Horizon without any Elevation, as is manifest by the Figure, where the Point of the Equinoctial Æ is in the Vertex, and the Poles P, *p* in the Horizon. If we go from the Equator towards either of the Poles, the Equator will then appear to depart from the Vertex or Zenith, and to come nearer to the Horizon, making with it an oblique Angle; whence such a Situation is called an *oblique Position of the Sphere,* and the Pole towards which we move doth rise more and more above the Horizon the nearer we approach it. Its Elevation being always equal to the Latitude of the Place, while the other continues as much depressed below it. The Figure does clearly shew this sort of Position which we and all that live in the temperate Zones obtain, where the Equator Æ Q is bisected by the Horizon, as it is in a right *Sphere;*

Plate XVI. Fig. 5.

An oblique Sphere; *or an* oblique Position of the Sphere.

Fig. 6.

Sphere; wherefore when the Sun, by his apparent Diurnal Motion, describes this Circle, it makes the Day equal to the Night: But the Parallels of the Equator, in this *Oblique Position* are not cut into two equal Parts by the Horizon; but those which are towards the elevated Pole, each of them have a greater Portion above than under the Horizon: And as each Parallel is nearer the Pole, so much the larger Portion of it stands above the Horizon. But when the distance of the Parallel from the Pole becomes less than the Elevation of the Pole or the Latitude of the Place, then that Parallel, and all those included within it, are wholly above the Horizon, no part of them ever setting under it. The contrary happens in the Parallels which lye towards the depress'd Pole, a smaller Portion of them being above the Horizon, and the greater part lying under it. And those Parallels which are nearer to the depressed Pole than the Latitude of the Place, remain perpetually, together with the Stars included within them, under the Horizon, and are never visible to us. Hence it is necessary, since the Sun each Day describes by his apparent Diurnal Motion some Parallel, that from the Vernal Equinox to the Summer Solstice, the Days growing longer and longer, will be continually longer than the Nights; After the Solstice, tho' the Days continue till the Autumnal Equinox to be longer than the Nights, yet they become shorter and shorter, and at the Equinox they but just equal the Nights: From thence to the Winter Solstice the Days continually become shorter than the Nights, and are the shortest when the Sun is in that Solstice; but as the Sun leaves it they increase again, and in the Vernal Equinox the Day is as long as the Night.

IN an *Oblique Sphere* the Stars all obliquely rise and set. And as the *Right-Ascension* of a Star is the Arch of the Equator contained between the first of *Aries* and that Point which comes to the *Meridian* with the Star, or that Point which in a *Right Sphere* rises with the Star. So the Oblique Ascen-

Lecture XIX. Aſcenſion is the Arch of the Equator between the firſt of *Aries* and that Point of the Equator which riſes together with the Star in an *Oblique Sphere*, and numbered from *Weſt to Eaſt*, which according to the Obliquity of the *Sphere* is various. The Difference between the Right and the oblique Aſcenſion is called the *Aſcenſional Difference*.

IN an *Oblique Sphere* there is one Parallel as much diſtant from the elevated Pole, as the Place is from the Equator, which is called the Circle of *Perpetual Apparition*, or the biggeſt of all thoſe which conſtantly appear, which is ſuch, that all Stars incloſed within it never either riſe or ſett; tho' they ſometimes riſe higher, ſometimes deſcend lower towards the Horizon. Towards the other Pole there is another Circle oppoſite to this, which is the Circle of *Perpetual Occultation*, within which all the Stars that are contained never riſe, but conſtantly lye hid under the *Horizon*, and ſo are not to be ſeen.

A Parallel Sphere.

Plate XVI. Fig. 7.

IF the Equator makes no Angle with the Horizon, but thoſe two Circles coincide; In ſuch a Situation the Pole and Vertex coincide, and all the Parallels of the Equator become Parallels to the Horizon; And ſuch a Situation is call'd a *Parallel Sphere*, in which no fixed Stars do ever either riſe or ſett, but turn round in Circles Parallel to the Horizon. And when the Sun enters the Equinoctial, it then glides the whole Day along the Horizon. When he riſes towards the elevated Pole he never ſetts, but makes a very long Day of ſix Months: But when he goes from the Equinoctial towards the depreſſed Pole, he never riſes, and then there is a conſtant Night of ſix Months length. This Poſition of the *Sphere* belongs only to them who live at the Pole, if any are ſo miſerable as to have ſuch a place for their Habitation.

Climates and Parallels.

THE antient Geographers divided the *Earth* by Climates and Parallels; for they who live under the Equinoctial, being in a Right *Sphere*, have their Days and Nights equal: If we remove from thence

Lecture XIX.

thence towards either Pole, the Days in Summer become longer than the Nights, and the nearer we approach the Pole, the greater is the Difference between Day and Night, when the Day is at the longeſt; till we come under the Polar Circles, where there is no Night at all. Hence the Geographers did ſo divide the Earth by ſuch Parallels as made the longeſt Day encreaſe by quarters of an Hour; that is, each Parallel was ſo far diſtant from the next, that the longeſt Day in the more remote from the Equator, was a quarter of an Hour longer than that Day at the Parallel nearer to the Equator: And therefore reckoning the Equator as the firſt Parallel, the ſecond Parallel paſſed thro' thoſe Parts of the Earth, where the longeſt Day was twelve Hours and a quarter long. Under the third Parallel the longeſt Day was twelve Hours and two Quarters. In the fourth, the longeſt Day was twelve Hours and three quarters, &c. Now two ſuch Parallels made up a Climate, which were therefore diſtinguiſhed by the longeſt Day encreaſing half an Hour from the one to the other. Now the Exceſs of the Solſtitial Day above twelve Hours may grow ſtill bigger, till we come to the Polar Circle, where the Sun not ſetting makes the Day twenty-four Hours long, which is greater than the Equinoctial Day of twelve Hours by twenty-four half Hours, or forty-eight quarters of an Hour. From hence we gather that the number of Climates between the Equator and Polar Circle muſt be twenty-four, and the number of the Parallels forty-eight.

The riſing and ſetting of the Stars Coſmical, Acronycal, and Heliacal.

Becauſe the Civil Year of the Antients did not keep pace or agree with the apparent annual Motion of the Sun; having the Day of the Month, and the Year when any memorable Action fell out, it could not be from thence immediately known in what Seaſon of the Year it was done. And therefore when the Husbandmen ſettled the Times for the ſeveral diſtinct parts of their Buſineſs, they could not point out that Time by a certain Day of their *Kalendar*; for the ſame

Day

Lecture XIX. Day of the Month was not always in the same Season of the Year, but it was necessary to have more certain Characters and marks to distinguish Times; and therefore the Writers of Husbandry, Historians and Poets had recourse to the risings and settings of the *Stars*, by them to mark out the Times. And of these risings and settings they reckoned three sorts *viz*. The *Cosmical*, *Acronychal* and *Heliacal*. A *Star* is said to rise or sett *Cosmically* which rises or setts when the *Sun* rises; so that a *Star* which rises or setts in the Morning rises or setts *Cosmically*. A *Star* rises *Acronychally* when it rises while the *Sun* setts, that is in the Evening when it is in Opposition to the *Sun*, and is visible all Night.

A *Star* rises *Heliacally*, when after it has been in Conjunction with the *Sun*, and on that account invisible, it comes to be at such a distance from him, as to be seen in the Morning before *Sun* rising, when the *Sun* by his Apparent Motion recedes from the *Star* towards the *East*. But the *Heliacal* setting is when the *Sun* approaches so near a *Star* that it hides it with his Beams, which keep the fainter light of the *Star* from being perceived. And therefore the *Heliacal* rising and setting is rather an Apparition and Occultation than a rising and setting.

ALL the *fixed Stars* in the *Zodiack*, as likewise the Superiour Planets *Mars*, *Jupiter* and *Saturn* rise *Heliacally* in the Morning a little before Sun rising, and a few Days after they have sett *Cosmically*; because the *Sun* in his Apparent Motion gets before them, moving faster *Eastward*: But they set *Heliacally* in the Evening a little before their *Acronychal* setting. But the *Moon* whose Motion *Eastward* is always quicker than the Apparent Motion of the *Sun*, rises *Heliacally* in the Evening, after the new *Moon* or the Change, when it can be first discovered at *Sun* setting; but the *Moon* setts *Heliacally* in the Morning when the *Moon* is old and approaching to a Change. The Inferiour *Planets Venus* and *Mercury*, which some-

times

times seem to go *Westward* from the *Sun*, and sometimes again have a quicker Motion than he *Eastward*, rise *Heliacally* in the Morning when they are Retrograde; but when they are direct in their Motions they rise *Heliacally* in the Evening. Lecture XIX.

FOR to observe the Altitude of the *Sun* or any *Star*, we use a moveable Quadrant EAD, with fixed sights A, B, or a Telescope placed along one of its sides, and a Plumb line AC hanging from its Center. The Quadrant being placed in a Vertical Plane must be turned upwards and downwards, till the Rays of the *Sun*, passing thro' the hole of the first Sight next the Center, fall upon the hole of the other; or till the *Sun*'s Image appears in the *Focus* of the Telescope, and then the Quadrant being kept in this Position, the Plumb Line or Thread will shew the Arch EC which measures the Altitude of the *Sun*. For produce AC to the *Zenith* Z, and let AH be an *Horizontal* Line. The Angles EAB and ZAH are equal being both Right; but the Angles BAC and ZAS are likewise equal, they being vertical to each other: wherefore taking away equal Angles, there will remain the Angle EAC equal to the Angle SAH. But the Arch EC measures the Angle EAC, and the Arch of the Vertical between the *Sun* and the *Horizon* measures the Angle SAH; and therefore this Arch or the *Sun*'s Altitude and the Arch EC are similar or like Arches. But if the height of a *Star* be to be observed, instead of the Irradiation of Beams as in the *Sun*, we must look thro' both Sights, or the Telescope for the *Star*; and when we can so see it, then the Thread will shew the Altitude of the *Star*. The Meridian Altitude of the *Sun* or *Star* is known by observing when the Altitude is greatest, for then the *Sun* or *Star* attains his greatest height, being then in the Meridian.

How to observe the Altitude of the Sun *or of a* Star.

Plate XVII. Fig. 1.

THE knowledge of the Latitude of the place is the Foundation of all *Astronomical* Observations, without which we can know nothing, and therefore it is first accurately to be obtained, and be-

How to observe the Latitude of a Place.

Lecture XIX.

cauſe we have ſhewed the Altitude of the *Pole* to be always equal to the Latitude, we can beſt find our Latitude by obſerving the *Pole*'s height. But becauſe the *Pole* is only a Mathematical Point, and no ways to be perceived by our Senſes, we cannot find its height by the ſame Method as we did that of the *Sun* or *Stars*. And therefore we muſt take another way for finding it.

The Invention of the Meridian Line.

And firſt we muſt find the Section of the Plane of the Meridian with the *Horizon*, which Section is called the Meridian Line. This is obtained by erecting a *Gnomon* or Perpendicular upon the *Horizon* for to caſt a Shadow, and at the Foot of the *Gnomon*, at that Point which is directly under the top Point which caſts the ſhadow, there muſt be deſcribed a Circle, on whoſe Circumference the Shadow of the top Point may fall before Midday, and that Point of the Circumference where the Shadow comes muſt be carefully marked. Again after Midday obſerve the Point where the Shadow comes again to the ſame Circumference; and let the Arch between the two Points of Shadow be biſected, or cut into equal Parts. A Line drawn from the Center to the Point of Biſection will be the Meridian Line: For the *Sun* before and after Midday being equally high, is equally diſtant from the Meridian, or is in two Vertical Circles which make on each ſide equal Angles with it. Place therefore the Quadrant on the Meridian Line, ſo that its Plane may be in the Plane of the Meridian, and then take ſome *Star* near the *Pole* which never ſetts, and obſerve both its greateſt and leaſt Altitude. Let the greateſt be S O and the leaſt *s* O; the difference of their Altitudes is the Arch *s* S, the half of which P S or P *s*, deducted from the greateſt Altitude S O, or added to the leaſt *s* O, will give P O the Altitude of the *Pole* above the *Horizon*, which is equal to the Latitude of the Place.

Plate XVII. Fig. 2.

If the Theory of the *Sun* be known, from his Declination we may find out the Latitude of the place in this manner: Obſerve the Meridian diſtance of the *Sun* from the Vertex or *Zenith*, which is always the

the Complement of his Altitude; and add to this the Sun's Declination, when the Place and he are on the same side of the Equator; or substract the Declination when they are on different sides, the Sum or Difference is always equal to the Latitude: But when the Declination of the Sun is greater than the Latitude of the Place, which is known from the Sun's being nearer to the Elevated Pole than the Vertex of the Place is, as it will often happen in the Torrid Zone; then the Difference between the Sun's Declination and the Sun's Zenith Distance is the Places Latitude.

Lecture XIX.

HAVING once found out the Latitude of the Place, the Obliquity of the Ecliptick, or its Inclination to the Equator is easily obtained, by observing about the Summer Solstice the Sun's least Distance from the Vertex: If this Distance be substracted from the Latitude of the Place, when the Place is nearer to the Pole than the Sun is, the remainder will shew the greatest Declination of the Sun, which is equal to the Obliquity of the Ecliptick. Most Astronomers make the greatest Declination of the Sun, or the Obliquity of the Ecliptick to be 23 $\frac{1}{2}$ Degrees; but the more accurate Observations of our Modern Astronomers shew it to be one Minute less.

How to observe the Obliquity of the Ecliptick.

BY the same Method, the Declination of the Sun for any Day, or that of a Star may be taken; for when the Sun or Star is nearer to the Equator than the Place, take the Difference between the Latitude of the Place and the Meridional Distance of the Sun or Star from the Vertex, and we shall have the Declination: But if the Vertex of the Place lye between the Sun or Star and the Equator, then the Sum of these two Quantities is the Declination.

How to find the Declition of the Sun or Star.

HAVING the Declination of the Sun, it is easy to find his Right Ascension and Place in the Ecliptick, by the Solution of a Right Angled Spherical Triangle. For let Æ Q be the Equator, Æ C the Ecliptick, S the Sun: from which let fall on the Equator a Circle of Declination S D, and

To find the Sun's Right Ascension.

Plate XVII. Fig. 3.

Lecture XIX. and then the Arch S D will be the Sun's Declination. And therefore in the Right-Angled Triangle Æ S D we have S D and the Angle Æ: We can therefore from thence find by ſpherical *Trigonometry* the Arch Æ D, which is the right Aſcenſion of the Sun, and Æ S, which gives his Place in the Ecliptick; and likewiſe the Angle Æ S D, the Inclination of the Circle of Declination or of the Meridian with the Ecliptick. So likewiſe in the Right-Angled Triangle Æ S D, if we have the ſide Æ D, which is the Right Aſcenſion, the Angle Æ being conſtant and known, we may eaſily find the ſide S D, which is the Declination of the Point of the Ecliptick S, which comes to the Meridian together with D, and is then call'd the *Medium Cœli*, or Mid-heaven; as alſo the Angle Æ S D the Inclination of the Meridian to the Ecliptick. Or laſtly, if Æ S the Longitude of the Point S be known, we can from it find its Right Aſcenſion and Declination, together with the Angle D S C, of the Ecliptick and Meridian.

The Apparent Motion of the Sun in the Ecliptick is not equable.

IF the Declination of the Sun by the Method we have ſhewed be daily obſerved, we can from thence collect the Apparent Motion of the Sun in the Ecliptick, which is always equal to the Motion the Earth really has in the ſame time. Now by Obſervation we find that the Sun does not move equably, or always with the ſame Velocity in the Ecliptick: And therefore the real Motion of the Earth muſt be unequal, and not conſtantly the ſame; in the Summer Solſtices the Earth has a ſlower Motion, in the Winter time it moves quicker: And this happens, becauſe the Earth by its real Motion is carried in the Perimeter of an Ellipſe, which has the Sun in one of its *Foci*; round which it revolves in ſuch a manner, that a Line drawn from the Sun to the Earth, and by an Angular Motion carrying the Earth along with it, doth always ſweep or deſcribe Elliptick *Area's* or Spaces proportional to the times in which they are deſcribed.

HAVING the Place of the Sun in the Ecliptick, by the help of it, and a good Pendulum Clock, we may find the Right Ascensions of all the Stars: For which purpose the Motion of the Clock must be so adjusted, that the Hand may run thro' the twenty-four Hours in the time that a Star leaving the Meridian will arrives at it again; which Time is somewhat shorter than the Natural Day, because of the Space the Sun moves thro' in the mean time Eastward. The Clock being thus adjusted, when the Sun is in the Meridian fix the Hand to the Point, from whence we are to begin to reckon our Time; And then observe when the Star comes to the Meridian, and mark the Hour and Minute that the Hand then shews: The Hours and Minutes describ'd by the Index turn'd into Degrees and Minutes of the Equator, will give the Difference between the Right Ascension of the Sun and Star; which Difference being added to the Right Ascension of the Sun, will give the Right Ascension of the Star. Now if we know the Right Ascension of any one Star, we may from it find the Right Ascensions of all the others which we see, by marking the Time upon the Clock between the arrival of the Star whose Right Ascension we know to the Meridian, and another Star whose Ascension is to be found. This Time converted into Hours and Minutes of the Equator, will give the Difference of Right Ascensions; from whence, by *Addition*, we collect the Right Ascension of the Star which was to be found out.

Lecture XIX.

To find the Right Ascension of the Stars.

BUT by knowing the Right Ascension of one Star, the Right Ascensions of the rest are easiest found by the following Method; where there is no need of waiting till the Stars come to the Meridian. We only use a Telescope, in whose *Focus* there are fixed four Threads extended, two of which as AB, CD cut one another at Right-Angles, and other two EF, GH make half Right-Angles with the former two, at their common Intersection O: Then the Telescope is to be directed to a Star, whose Right Ascension and Declination are known.

The Right Ascension of one Star being known; how from thence to find the Right Ascensions of the rest.

Lecture XIX.

Plate XVII. Fig. 4.

AND then the Telescope is to be constantly turned till the Star be seen in the Line A B, so as its apparent diurnal Motion may be along that Line; in which Position the Right Line A B will represent a Portion of that Parallel Circle the Star describes, it being in a parallel to its Plane: And because the Line C D cuts it at Right-Angles, it will represent some Horary Circle. Fix then the Telescope very firm in this Situation, and mark the Time according to the Clock, when the Star, whose Ascension is known, comes to the Line C D. Then again observe any other Star with the Telescope, which will appear to move in some Line L K that is parallel to A B, and mark likewise the time when it comes to the Horary Circle C D in Q. The Difference of Times between the arrival of the first Star to the horary Circle, and the coming of this last to the same, converted into Degrees and Minutes of the Equator, will give the Difference of their Right Ascensions: And therefore if the Right Ascension of one of them be found, we may from thence collect the Right Ascension of the other.

BECAUSE the Angles Q H O and Q O H are equal, being each half a right, Q H will be equal to Q O. Now if we mark the Time between the coming to the Thread O H, and its touching the Thread O Q, we shall have the time the Star takes to describe the Portion H Q of the Parallel. This Time being turned into Degrees and Minutes, will give the Number of Degrees and Minutes of the Portion Q H. But the Arch of the Horary great Circle is equal to this Arch Q H. Now in unequal Circles the Degrees and Minutes that equal Arches contain are reciprocally as the Radii or Semidiameters of the Circles, as we shall shew hereafter. As the Radius therefore of the great Circle is to the Radius of the Parallel L K (which does not sensibly differ from the Radius of the known Parallel A B.) that is, as the Radius is to the Sine of the Stars distance from the Pole, so the Number of Degrees

and

and Minutes in the Arch H Q of the Parallel, to the Number of Degrees and Minutes in the Arch O Q of the great Circle; which therefore will be known by the Rule of Proportion. But Q O is the Difference of the Declinations of the Star which describes the Parallel A B and of that which describes the Parallel L K; therefore from the Declination of one of these Stars being known, we can find the Declination of the other. And by this Method the Right Ascensions and Declinations of most Stars may be observed. Lecture XIX.

THAT in unequal Circles the Numbers of similar Parts, as Degrees and Minutes, that are in Arches equal in bigness, are reciprocal to the Radii of the Circles, may be thus demonstrated. Imagine two unequal Circles whose Center is C, and in them equal Arches B E, A F: Draw from the Center C B, C E, cutting from the lesser Circle the Arch A D. The Arches A D and B E will contain equal Numbers of Degrees and Minutes. And because A F and B E are equal, A D will be to A F as A D is to B E. But A D is to B E as C A is to C B; therefore A D will be to A F as CA is to C B. But A D is to A F as the Number of Degrees and Minutes in A D or in B E is to the Number of Degrees and Minutes in A F. Wherefore the Number of Degrees and Minutes in B E is to the Number of Degrees and Minutes in A F, as C A is to C B; or in a reciprocal Proportion of the Radii of the Circles. Which was to be demonstrated. Plate XVII. Fig. 5.

Having the Right Ascension of a Star, and its Declination to find its Longitude and Latitude.

HAVING the Right Ascension and Declination of a Star, its Longitude and Latitude may be found out by the Solution of a spherical Triangle. For imagine B P Q to pass thro' the Poles of the Equator and Ecliptick; this Circle is the *Solstitial Colure.* Let Æ Q be the Equinoctial, E C the Ecliptick, whose Section with the Equinoctial is ♈, and let S be a Star, thro' which passes the Circle of Declination P S F, cutting the Equinoctial at F: The Arch ♈ F is the Right Ascension of the Star, and S F its Declination. Plate XV. Fig. 6.

 Draw

Lecture XIX. Draw thro' the Pole of the Ecliptick B and the Star the Circle of Latitude B S O, meeting with the Ecliptick in O: Then ♈ O will be the Longitude of the Star, and S O its Latitude. In the ſpherical Triangle B S P, we have the ſide P S which is the Complement of the Declination, and the ſide B P, which is equal to the Arch that meaſures the Inclination of the Equator and the Ecliptick: Beſides which, we have the Angle which is meaſured by the Arch F Q the Complement of the Right Aſcenſion; and therefore we have the Angle B P S its Complement to two right Angles. And therefore in the Triangle B P S having three of its conſtituent Parts, we may find firſt the Angle P B S, whoſe meaſure is the Arch O C, and its Complement to a Quadrant is the Arch ♈ O, which is the Longitude of the Star. We can likewiſe from the ſame Things given find the Arch B S, whoſe Complement to a Quadrant is S O, the Latitude of the Star. After the ſame Method, if the Longitude and Latitude of a Star be known, we may from thence find its Right Aſcenſion and Declination.

By comparing the Places of the fixed Stars, as they were deliver'd to us by the Antients, with what they now obtain, we find that their Latitudes are much the ſame they were formerly; but their Longitudes or Diſtances from the firſt of ♈ have been found to encreaſe continually: Not that the Stars have a real progreſſive Motion; but becauſe the Equinoctial Points have a Motion backwards, and the Longitudes are computed from them. The Longitude of any fixed Star obſerved by the Antient Aſtronomers, compared with the Longitude it has at preſent, ſhews the Quantity of this Regreſſion of the Equinoctial Points to be about one Degree in 72 Years.

BY the Method we have ſhewed, the Longitudes and Latitudes of the Fixed Stars are found, and they and their Places are ranked in a Catalogue, which being once eſtabliſhed, the Places of the Planets and Comets are eaſily known by Ob-

ſervations

ſervation and Computation. For if the Diſtances of any Planet or Comet from two Fixed Stars of known Longitude and Latitude be taken by Obſervation, we may by that means determine the Longitude and Latitude of the Planet or Comet in the following manner. Lecture XIX.

Let E F be a Portion of the Ecliptick, whoſe Pole is B, and let A and C be two Stars, whoſe Longitudes and Latitudes are known, and P a Planet, whoſe Diſtances from the ſame Stars are known by Obſervation. In the Triangle A B C, having A B and C B the Complements of the Latitudes of the two Stars, and the Angle A B C, whoſe meaſure is the Arch E F, the Difference of Longitude of the two Stars; from thence we may find A C the Diſtance of the Stars, and the Angle B C A. Again, in the Triangle A P C we have all the Sides, from which we may find the Angle PCA; which being ſubſtracted from BCA, will leave the Angle B C P. Laſtly, in the Triangle B C P, we have the ſides B C, C P, and the Angle P C B; from which we can find the Angle P B C, whoſe meaſure is O F the Difference of Longitude of the Star C and the Planet. We can alſo find the Arch P B the Complement of the Latitude of the Planet. Plate XVII. Fig. 7.

AFTER the ſame Method, if we have the Diſtances of a Planet from two Fixed Stars, whoſe Right Aſcenſions and Declinations are known, we may find out the Right Aſcenſion and Declination of that Planet.

LECTURE XX.

Of the Twilight, *and of the Refraction of the Stars.*

The Air makes the Firmament lucid.

BESIDES other innumerable Conveniencies which we receive from the *Atmosphere*, we have this great Advantage, that while the Sun shines, it makes the Face of the Heavens or Firmament to appear lucid and bright; for if no *Atmosphere* surrounded and involved the Earth, only that part of the Heavens would appear to shine in which the Sun was placed: And a Spectator, if he should turn his Back to the Sun, would immediately perceive it as dark as Night; and even in the Day-time while the Sun shined, the least Stars would be seen shining, as they do now in the clearest Night; since in that Case there would be no substance to reflect the Rays of the Sun to our Eyes, and all the Rays which do not fall upon the Surface of the Earth, passing by us, would either illuminate the Planets and Stars, or spreading themselves out into infinite Space, would never be reflected back to us.

BUT since there is an *Atmosphere* covering the Earth, which is strongly illuminated by the Sun, it reflects the Light back upon us, and makes the whole Heavens to shine; and that so strongly, that by reason of its Splendor, it obscures the faint Light of the Stars, and renders them invisible.

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Plate XVII.

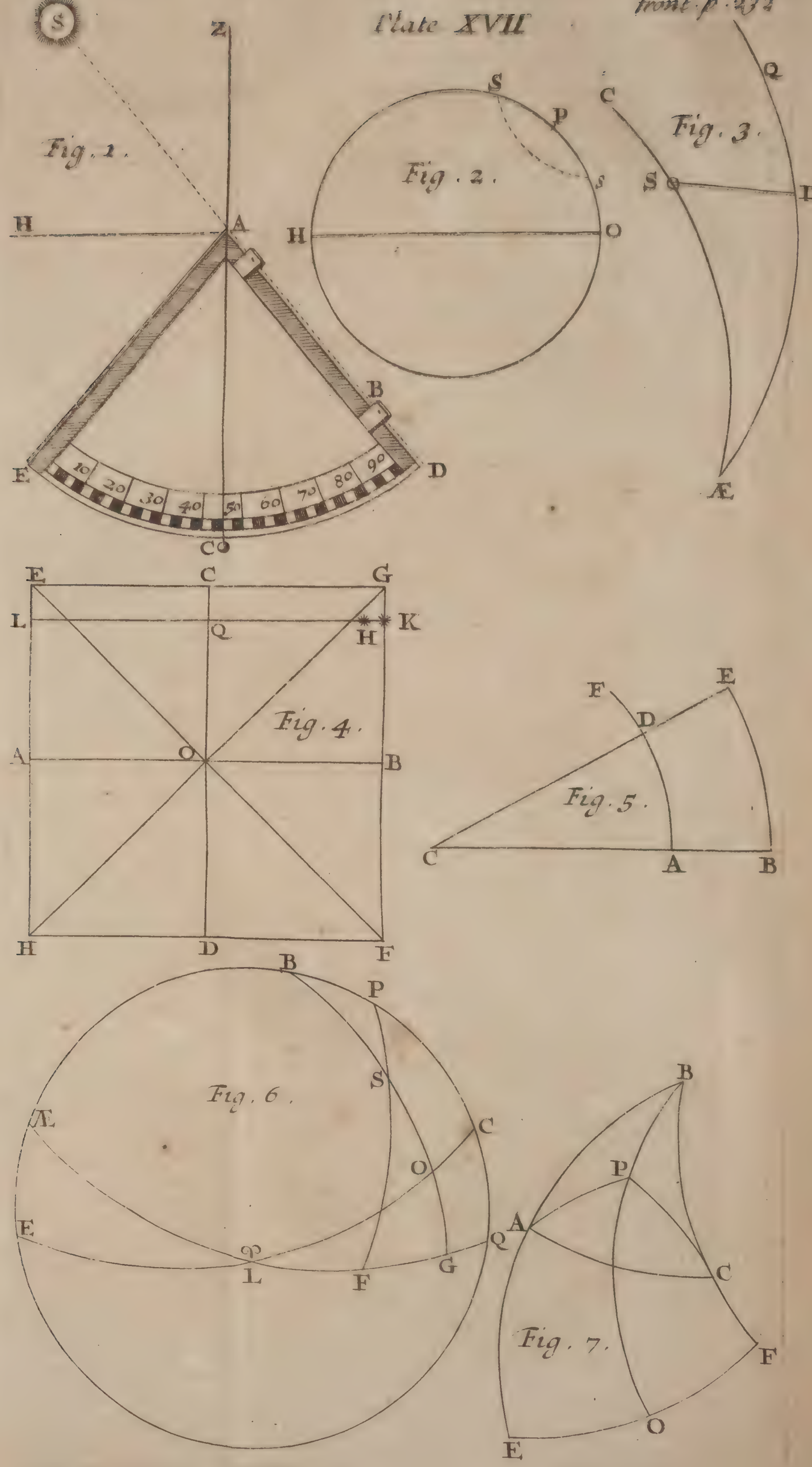

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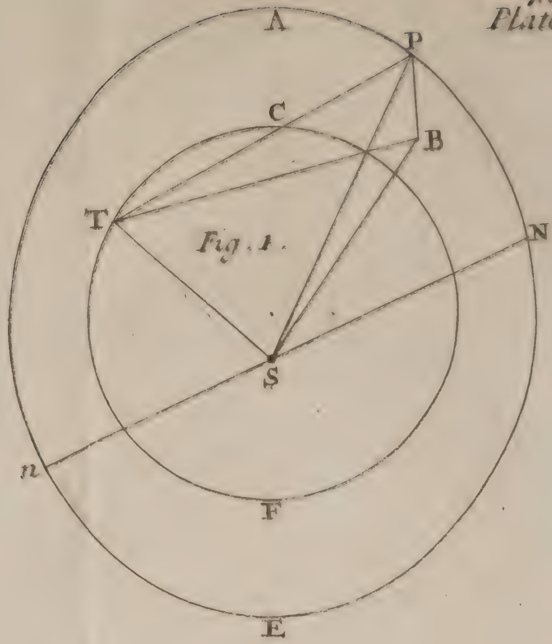
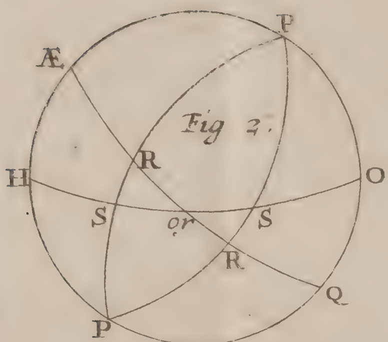
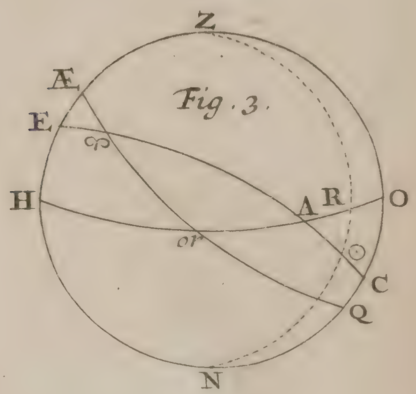
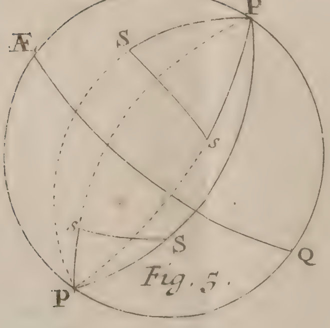
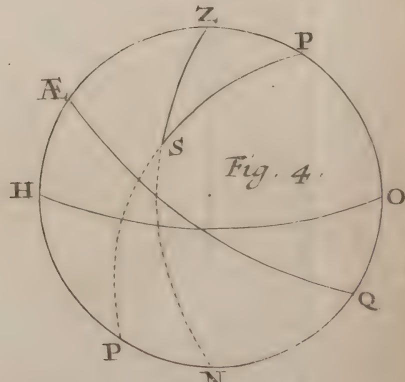
Plate XXVI











Lecture XX.

IF there were no *Atmoſphere*, the Sun immediately before his ſetting, would ſhine as briskly as at Noon; but in a Moment, as ſoon as he is ſet, we ſhould have the Face of the Earth in as great Darkneſs as it would be at Midnight: So quick a Change, and ſo ſuddain a paſſing from the greateſt Light to the greateſt Darkneſs, would be very inconvenient to the Inhabitants of the Earth. But by means of the *Atmoſphere* it happens, that tho' after Sun ſetting we receive no direct Light from the Sun, yet we enjoy its reflected Light for ſome Time; ſo that the Darkneſs of the Night comes not ſuddainly, but by Degrees. For after the Earth by its Revolution round its Axis has withdrawn us from the ſight of the Sun. The *Atmoſphere* which is higher than we are, will ſtill be illuminated by the Sun; ſo that for a while the whole Heavens will have ſome of his Light imparted to it. But as the Sun goes ſtill lower under the Horizon, the leſs is the Air illuſtrated by him: So that when he is got as far as 18 Degrees lower than the Horizon, he no longer enlightens our *Atmoſphere*, and then all that part thereof that is over us becomes dark.

The Cauſe of the Crepuſcles.

SO likewiſe in the Morning, as ſoon as the Sun comes within 18 Degrees of the Horizon, he begins again to enlighten the *Atmoſphere*, and to diffuſe his Light thro' the Heavens: So that its Brightneſs does ſtill increaſe, till the Sun riſes and makes full Day. This ſmall Illumination of the *Atmoſphere*, and ſtate of the Heavens between Day and Night, is what we call the *Twilight*, which is obſerved in the Morning before the Sun's riſing, and at Night after his ſetting; in *Latin* it is named the *Crepuſculum*.

TO make this plainer, imagine the Circle A D L on the Surface of the Earth, in the Plane of the vertical Circle in which the Sun is when under the Horizon. Let there likewiſe be another concentrical Circle C B M in the ſame Plane, including that Portion of the Air that reflects the Sun's Beams: And ſuppoſe the Eye to be on the Earth's

Plate XIX. Fig. 1.

Lecture XX.

Earth's Surface at A, whose sensible Horizon is A N. Since no Line can be drawn to A between the Tangent A N and the Periphery A D, by the 16th of the *Third Element*; it is plain, that when the Sun is under the Horizon no direct Rays can come to the Eye at A: But the Sun being in the Line C G, a Line may be drawn from him to C, so that the Particle C may be illuminated by the direct Rays of the Sun; which Particle may reflect those Rays to A, where they may enter the Eye of the Spectator: And by this means the Beams of the Sun's Light illuminating an innumerable multitude of Particles, may by them be reflected to the Spectator in A. Let the Tangent A B meet with the Surface of the Orb of Air that reflects the Light in B; and from B draw B D, touching the Circle A D L in D, and let the Sun be in the Line B D at S: Then the Ray S B will be reflected into B A, and will enter the Eye, because of the Angle of Incidence D B E being equal to the Angle of Reflection A B E: And that will be the first Ray that reacheth the Eye in the Morning, and then the dawning begins; or the last which falls upon the Eye at Night, when the *Twilight* ends. For when the Sun goes lower down, the Particles at B can be no longer illuminated.

Another Cause of the Twilight.

THE Reflection of the *Atmosphere* does not seem to be the only cause of the *Twilight*; but there is an Ætherial Air or *Atmosphere* likewise round the Sun, which shines after the Body of the Sun is set: This Orb of the Sun's *Atmosphere* rising sooner, and setting later than the Sun it self, shines out at Mornings and Nights in a circular Figure, it being a Segment of the Sun's *Atmosphere* cut by the Horizon; and its Light is quite of another sort than that which is made by the Reflection of our *Atmosphere*. But the Duration of the *Twilight* that arises from the Sun's *Atmosphere*, is shorter much than that made by the Reflection of the Earth's *Atmosphere*, which does not end till the Sun comes to be 18 Degrees below the Horizon,

zon, or thereabouts. But there can be no certain bounds fixed for the Beginnings and Endings of the *Twilights*; for their Lengths depend on the quantity of Matter in the Air which is able to reflect Light, and on the Height of the *Atmosphere*. In the *Winter* the Air being condensed by the cold is low, and on that Account the *Twilights* are sooner over. In the *Summer* the Air is rarify'd by Heat, and therefore being higher remains longer illuminated by the Sun, so that the *Twilights* last the longer: Also the Duration of the *Twilight* is shorter in the Morning than at Night. We generally reckon that the *Twilight* begins or ends, when in the Morning the Stars of the sixth Magnitude disappear, or in the Evening when they first come to be seen; the light of the Air before that rendring them invisible. *Ricciolus* observed at *Bononia* that the Morning *Twilight* about the Time of the *Equinoctes*, lasted an Hour and 47 Minutes; but in the Evening two Hours, and did not end till the Sun was 20 Degrees under the Horizon: But in *Summer* the Morning *Twilight* was three Hours and 40 Minutes long; the Evening *Twilight* scarcely ending till Midnight.

The Height of the Atmosphere *measur'd by an Observation of the* Twilight.

HENCE if we have the Time of Beginning of the *Twilight* in the Morning, or the end of it at Night, we may find the Height of the Air that reflects the Light; for then the *Twilight* ends, when a Ray of Light from the Sun touches the Globe of the Earth, and is by the highest Air reflected to our Eyes: For having the Time, we can find the Depression of the Sun below the Horizon, and from thence the Height of the Air. For let S B be a Ray of Light touching the Earth, which is reflected, by a particle of Air in its highest Region, in the horizontal Line A B; the Angle S B N is the measure of the Depression of the Sun below the Horizon: And because A B is also a Tangent, the Angle A E D at the Center is equal to the Angle S B N; and its half, that is the Angle A E B, is equal to half S B N or half the Depression of the Sun. Suppose the Depression

Lecture XX. ſion of the Sun at the beginning or end of *Twilight* be 18 Degrees; then the Angle A E B will be 9 Degrees, which would be true, did the Ray S B paſs thro' the *Atmoſphere* without Refraction: But becauſe it is refracted and bent towards H, we muſt diminiſh the Angle A E B by a quantity equal to the Horizontal Refraction, which is about half a Degree: And therefore the true meaſure of the Angle A E B is $8\frac{1}{2}$ Degrees. Moreover, A E is to B H as the Radius is to the exceſs of the Secant of the Angle A E B above the Radius, that is as 100000 is to 1110. Therefore if the Semidiameter of the Earth be in round Numbers 4000 Miles, B H the height of the *Atmoſphere* which reflects the Sun's Rays will be about 44 Miles; for as 100000 is to 1110, ſo is 4000 to 44.

Under the Equator the time of the Twilight *is ſhort.*

IN a right Poſition of the Sphere the *Twilights* are quickly over; becauſe the Sun deſcends conſtantly nearly in a perpendicular; but in an oblique Sphere they laſt longer, the Sun deſcending obliquely; and the more oblique the Sphere is, that is the greater the Latitude of the Place is, ſo much longer laſt the *Twilights*: So that all they who are in above 48 Degrees Latitude, in the *Summer* near the Solſtices, have their *Atmoſphere* illuminated the whole Night, and the *Twilight* laſts till the Sun-riſing, without any compleat darkneſs.

Under the Poles they laſt ſome Months.

IN a parallel Sphere the *Twilight* laſts for ſeveral Months; ſo that the Inhabitants have either the direct or reflex Light of the Sun for almoſt all the Year.

The Circle terminating Twilight.

IF below the Horizon you conceive a Circle to be drawn parallel to the Horizon, and at a diſtance from it equal to the Depreſſion of the Sun at the end of the *Twilight*: This leſſer Circle is called the *Circle which terminates the* Twilights; for whenever the Sun by its apparent diurnal Motion reaches this Parallel, the Morning *Twilight* begins, or the Evening ends, in whatever parallel of the Equator the Sun is.

IN

IN the Figure let HQO be the Horizon, VaX the Circle parallel to it terminating the *Twilight*, the Circle HZO the Meridian, ÆQa the Equator. It is manifest that the more oblique the Equator is to the Horizon, so much the greater are the Arches of the Equator and its Parallels, intercepted between the Horizon and the terminating Circle VaX. The Arches QR, *da*, C*e*, G*h*, K*l*, are called the Arches of the *Twilights*, because they determine their Duration: And as each Arch has a bigger or less proportion to its Circle, so will the *Twilight* when the Sun is in that Parallel, be longer or shorter. In the Circle bounding the *Crepuscles* take any Point *a*, thro' which passes a Parallel to the Equator *da*; and thro' *a* imagine a great Circle to be drawn as M*a*N, touching the Circle of perpetual Apparition: And since the Horizon likewise touches the same Circle, these two Circles will make equal Angles with the Equator and its Parallels; for the measure of each Angle is the distance of the Parallel from its great Circle. So likewise all the Arches of the Equator, and its Parallels between the Horizon and the Circle M*a*N are similar, by *Prop.* 13, Book II. *Theodosius*'s Sphericks. This Circle M*a*N will either cut the bounding Circle V*a*X in two Points, or touch it in one. Let it first cut it in two Points *a* and *h*; and therefore the Arches of the Parallels *da*, G*h* are similar: Wherefore when the Sun by its diurnal Motion describes these two Parallels, the *Twilights* are equal; But while he describes any intermediate Parallel as C*e*, the Time of the *Twilight* is shorter; for in this case C*m* the Arch of *Twilight* is less than C*e*, which is similar to the Arch *da* or G*h*, and C*e* and *da* are described by the Sun in equal times. But when the Sun is in Parallels that are at a greater distance from the Equator than G*h*, the *Twilights* last longer; for the *Twilight* Arch *l*K is greater than *q*K, which is described by the Sun in the same time as the Arch of the *Crepuscle* G*h*.

Lecture XX.

The Arches of the Crepuscles *or* Twilight.

Plate XIX. Fig. 2.

WHILE

Lecture XX.

WHILE the Sun is in Parallels that are towards the elevated Pole, the *Twilights* do constantly grow longer, according as those Parallels approach the Poles: For the *Twilight* Arch *o p* is longer in being described than Q R, and Y U the same way is longer than *o p*. But if the Sun describe the Parallel S *t*, it never will meet with the bounding Circle, and then the *Twilight* lasts the whole Night long.

The different Durations of the Twilights.

HENCE arises a great Difference between the increase of the *Twilight* and its decrease and the encreale and decrease of Days and Nights. For while the Sun moves from the beginning of ♋ to the first of *Capricorn*, all that time the Days constantly decrease, and the Nights increase: But in the *Twilight* it is otherwise; for tho' the *Twilight* and Days are at the longest when the Sun is in the first degree of ♋, and then they both decrease together; yet the times of *Twilight* do not continually decrease till the Sun comes to ♑, but there is a certain Point between ♎ and ♑, to which when the Sun arrives, we have the shortest *Twilight*. From thence the *Twilights* will begin to encrease again, and there will be one Arch of *Twilight* similar to that when the Sun is in the Equator, before he reaches ♑: And if the Sun should go further South even beyond the Tropick, the *Twilights* would still increase, altho' the Days decreased. And altho' the Days from the beginning of the Sun's entry into ♑ do constantly encreale, yet the *Twilights* grow shorter till the Sun comes to a point between ♑ and ♈, in which again we have the shortest *Twilight*: This appears plain by what we are here to demonstrate in the next place.

Plate XIX. Fig. 3.

2*dly*, LET the Circle M *a* N touch the bounding Circle in one point, which suppose to be *a*, thro' which draw the Parallel to the Equator *d a*; I say that when the Sun is in this Parallel the *Twilight* will be the shortest of all. For because the Arches of the Parallels intercepted between the Horizon and the Circle M *a* N are all similar,

they

they will be deſcribed by the Sun in equal times: But becauſe the *Twilight* Arches *c e* and *g b* are greater than *c m* or *g i*, the Sun will be longer in moving thro' the Arch *c e* than *c m*, and thro' the Arch *g b* than *g i*; that is longer than in deſcribing the Arch *d a*, which Arch therefore is the ſhorteſt *Twilight*. Lecture XX.

The time of the ſhorteſt Twilight inveſtigated.

THE Diſtance of that Parallel from the Equator in which is the ſhorteſt *Twilight*, is thus inveſtigated. Becauſe the Circle M *a* N and the Horizon H O touch the ſame Parallel, which is the Circle of perpetual Apparition, they will both be equally inclined to the Equator: And therefore the Angle *a n* T of the Equator and the Circle M *a* N, is equal to the Angle F Q *d* of the Equator and the Horizon. Thro' the Zenith Z and the Point *a* draw the vertical Circle ZY*a*, cutting the Equator in the point T. The ſpherical Triangles *a n* T, T Q Y, are mutually equiangular to each other, becauſe the Angles at *a* and Y are right; and we have ſhewed that the Angles at Q and *n* are equal; alſo the Angles at T are equal, being vertical to each other: Theſe Triangles then being equiangular are alſo equilateral; and therefore T *a* will be equal to TY, or to half the diſtance of the bounding Circle from the Horizon: Moreover, *a n* is equal to Q *d*, by 13. *Prop.* Book II. *Theod.* for F R and *d a* are parallel, and therefore *d* Q is equal to Q Y.

IN the ſpherical Triangle T Q Y rectangular at Y, we have the ſide T Y half the diſtance of the bounding Circle from the Horizon; as alſo the Angle Y Q T equal to F Q *d*, which meaſures the Complement of the Latitude of the place; wherefore we can find Q Y, and Q *d* which is equal to it. From the Point *d* to the Equator draw the Circle of Declination *d* F; and in the ſpherical Triangle *d* Q F, we have *d* Q and the Angle Q, by which we can find the Arch *d* F, the Declination of the Parallel of the leaſt *Twilight* from the Equator, which was to be found.

THIS

Lecture XX.

The same Problem solved by a single Analogy.

THIS *Problem* might have been solved by one single Analogy. For in the Triangle TQY, the Radius : Tang. TY : : Co-tang. Q : Sin. QY or to the Sin. of *d*Q: But the Sin. of Q : Cosin. of Q : : Rad. Co-tang. Q. Therefore by the Rules of the 5*th* Element, The Rad. multiplyed by the Sin. of Q, will be to the Tang. of TY into the Cosin. of Q, as the Radius is to the Sin. of Q*d*: But in the Right-angled Triangle Q*d*F, Radius is to the Sine of Q*d* as the Sine of the Angle Q to the Sine of *d*F; wherefore Rad. × Sine Q will will be to Tang. of TY × Co-sine of Q, as the Sine of Q to Sine of *d*F; and thence, *ex æquo*, it will be as Radius to Tang. of TY, so Co-sine of Q or the Sine of the Latitude, to the Sine of the distance of the Parallel from the Equator. Having the Declination of the Sun, the time of the beginning of the Morning *Twilight*, which we call Break of Day, or the End of the Evening *Twilight* is thus to be found. Let *op* be the parallel of the Sun meeting with the bounding Circle in *p*; and draw thro' the Pole the Circle of Declination P*p*. In the spherical Triangle PZ*p* we have all the sides; for ZP is the Complement of the Latitude, P*p* the Complement of the Sun's Declination, and Z*p* equal to the Sum of a Quadrant and the distance of the bounding Circle from the Horizon $= Zl + lp$. From which we can find the Angle ZP*p*, and its Complement to two Rights *p*PV: and the Arch of the Equator measuring this Angle being converted into Time, will shew the beginning or end of *Twilight*.

The Duration of Twilight determined.

Refraction by the Atmosphere.

THE *TERRESTIAL ATMOSPHERE* by reflecting the Sun's Beams not only produces the Morning and Evening *Twilight*, but it also bends and refracts the Rays of the Sun and all the Stars which fall on it, and changes their Directions by propagating the Light in other Lines, making the apparent Places of the Stars different from their true Places.

BY manifold Experiments we find that the Rays of a luminous Body, even of any visible Object,

ject, when they fall upon a *Medium* or Diaphanous Body as Air or Water, of a different Density from that from whence they first proceeded; do not afterwards go directly in the same strait Lines, but are broken or bended, and propagated as if they had proceeded from another point than they really did. And if the *Medium* on which the Rays fall be denser than the first, they are bent towards a Line perpendicular to that Surface whereon they fall, at the point of Incidence; but if it be a *Rarer Medium*, in their bending they recede from the Perpendicular. Lecture XX.

WE observe in Nature many effects of Refraction. A Staff, whose one part is immerged in Water and the other in the Air, appears broken; and that part which is in Water appears higher than it really is. All the Stars by Refraction appear higher or nearer to our Vertex than they would be, were there no Air, so that the Light might arrive to us without Refraction.

LET ZV be a Quadrant of a vertical Circle in the Heavens described from the Center of the Earth T, under which is A B a Quadrant of a Circle on the Surface of the Earth, and G H a Quadrant on the surface of the *Atmosphere*: And let S be any Star from which proceeds the Beam of Light S E, falling on the Surface of the Air in E. Now since this Ray comes from the Etherial Air much rarer than ours, or rather from a perfect Void, and falls on our *Atmosphere*, which is dense in comparison of it; In E it will be refracted towards the Perpendicular: And because the upper Air is rarer than that which is nearer the Earth, and grows still denser the nearer it is to us, this Ray of Light as it proceeds will constantly be refracted and bended, so that it will arrive at our Eye in the curve Line E A: Suppose the right Line A F to touch this Circle in A; according to the Direction A F the Ray of Light will enter the Eye at A. And because all Objects are seen in the Line according to whose Direction the Rays enter the Eye and strike Plate XIX. Fig. 4.

Lecture XX.

upon the *Senforium*; the Objects will appear in the Line A F, that is in the Heavens at Q, which is nearer to our Vertex than the Star really is. And it may even happen, that a Star which is below the Horizon may be feen above it. This Refraction is alfo the caufe why the two great Luminaries the Sun and Moon, when one of them is above the Horizon and the other below it, both may appear above the Horizon; fo that the Moon has been obferved eclipfed, when fhe was below the Horizon and the Sun above it.

By Refraction an Eclipfe of the Moon may be feen when fhe is under the Horizon.

Where the Refraction is greateft; where the leaft.

A Star in the Vertex or Zenith has no Refraction, for a perpendicular Ray goes ftreight on; But the more obliquely the Ray falls upon the furface of the Air, fo much the greater is the Refraction; fo that the Horizontal Refraction is the greateft of all. And a Star that is above 50 Degrees high has fcarcely a fenfible Refraction. In equal Altitudes the Refractions are equal: And therefore the Sun, Moon and fix'd Stars, at the fame apparent height, have all the fame Degree of Refraction; tho' the noble *Tycho Brahe*, the Reftorer of *Aftronomy* and the firft obferver of Refractions, thought otherwife: Hence if the Refractions of the Fixed Stars are known, we fhall know likewife the Refractions of the Sun, Moon and Planets: And it is eafier to find by Obfervation the Refraction of a Fixed Star than that of the Sun and Moon: For the Parallaxes of thefe Bodies not being exactly known, the Obfervations about their Refractions will be doubtful; but the Fixed Stars having no Parallax, all the difference between their true and obferved Places is wholly owing to Refraction.

All the Stars at equal heights have equal Refractions.

The Method of obferving the Refraction.

Plate XIX. Fig. 5.

THOSE Fixed Stars that rife higher above the Horizon than 50 Degrees have their Declinations, Right-Afcenfions, Longitudes and Latitudes accurately enough known; for in fo great an Altitude the Refraction is next to nothing. Now thefe being known, we find the Refraction's near the Horizon by the following Method. Let O P Z H be the Meridian, H O the Horizon, Æ Q the Equa-

Equator, P the Pole, and the Vertex Z. Let A be a *Star* whose Refraction is to be found, and let Z D be a vertical Circle passing thro' the *Star*, whose apparent Place suppose to be C; the Arch A C is the Refraction. Let the apparent distance of the *Star* from the Vertex be observed, that is the Arch Z C: And at the time of the Observation take the Altitude of another *Star* which is so high that it is not liable to Refraction, with which find out the moment of Time the Observation was made; which may also be known by a good Pendulum Clock: By this Time and the Right-Ascension of the Sun, we shall find the Point of the Equator which then culminates or is in the Meridian, that is the Point Æ. But we have also the Right-Ascension of the *Star*, that is the Point B, where the Circle of Declination passing thro' the *Star* meets the Equator; and consequently the Arch Æ B will be known, which is the measure of the Angle Z P A. Therefore in the spherical Triangle Z P A, having Z P the distance of the Pole from the Vertex, and P A the Complement of the *Star's* Declination, as also the Angle Z P A, we find out by *Trigonometry* the side Z A the true distance of the *Star* from the Vertex; from which substract ZC the apparent distance known by Observation, and there will remain A C the Refraction of the *Star*, which was to be found.

Lecture XX.

Another Method for finding the Refraction.

THE Refraction may likewise be found by observing the Azimuth of a *Star*, or the Arch of the Horizon between the Meridian and the Vertical Circle passing thro' the *Star*, that is the Arch D O; for that Arch measures the Angle P Z A, from which, and the sides P Z, P A, we may find Z A the true distance of the *Star* from the Vertex, from which substract Z C the observed Distance, and we shall have C A the Refraction required.

The Method of observing the Azimuth of a Star. Plate XIX. Fig. 6.

THE Azimuth of any *Star* is best observed, by drawing on the Plane of the Horizon the Meridian Line A E; upon which erect the Perpendicular C A, which is easily perform'd by a Line and a Plummet: Then take another Thread

Lecture XX.

with a Weight as BD, and hang it so that the Body of the *Star* may be covered by the two Threads CA, DB, and then the *Star* will be in the Plane of a Vertical Circle, in which Plane the Threads do likewise stand: Mark then the Point B in the Plane of the Horizon, and in the Meridian Line the Point A, upon which is erected the Thread AC: And taking in the Meridian Line any Point E, draw AB, BE; then by the help of a Scale of equal parts measure the three sides of the Triangle BAE, from which by *Trigonometry* we shall find the Angle BAE, which is the Azimuth that was to be found.

FROM Refraction, the reason is plain why the Sun and Moon near the Horizon appear of an oval Figure; for their inferiour Limbs are more refracted and raised higher than the superiour Limbs are; and therefore these two Limbs will seem nearer to each other, and the breadth of the Bodies contracted, while both ends of the Horizontal Diameter being equally refracted and raised, keep the same distance from one another, and its apparent Magnitude remains the same.

When the Sun is in the Horizon its Rays pass thorough a larger space of Air than when he is in the Zenith.

THE Rays of the Sun, when he is in or near the Horizon, pass thorow a larger body of Air, than when he is near the Vertex. For let ABD be the Earth, ECF the Orb of Air which surrounds it, whose Altitude is commonly reckon'd to be 50 Miles. Let CA be an Horizontal Ray, EA a Vertical Ray: It is manifest that CA is longer than EA; and the proportion of these Lines may be thus found out. Suppose the Semidiameter of the Earth in round Numbers to be 4000 Miles, and EA 50; then is TE = CT 4050, whose Square is equal to the Squares of CA and AT: And therefore if from the Square of CT we take away the Square of TA, there will remain the Square CA; That is, if from 16402500 we substract 16000000, there will remain 402500, which is the Square of CA, whose Root is 634: And therefore CA : AE :: 634 : 50, which is greater than the proportion of 12 to 1. Hence we

Plate XIX. Fig. 7.

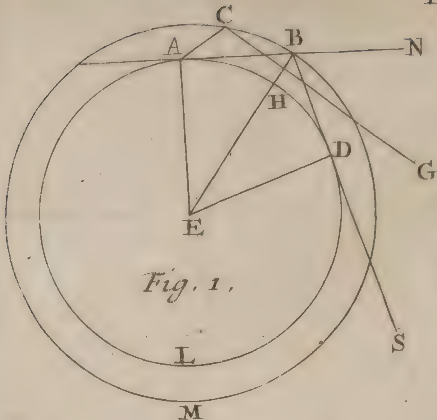


Fig. 1.

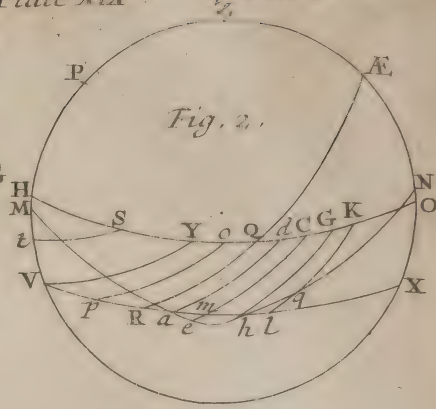


Fig. 2.

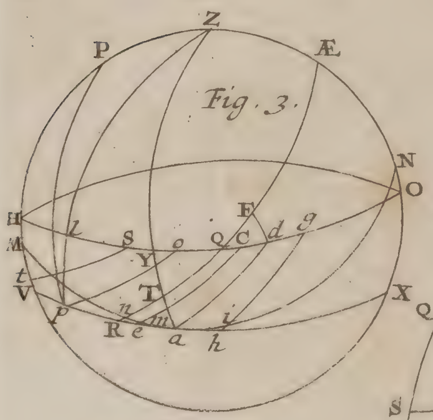


Fig. 3.

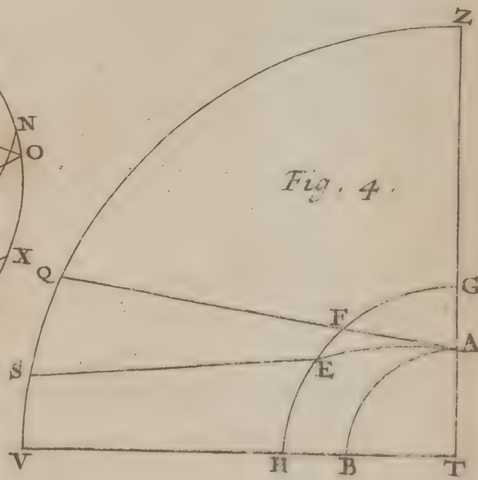


Fig. 4.

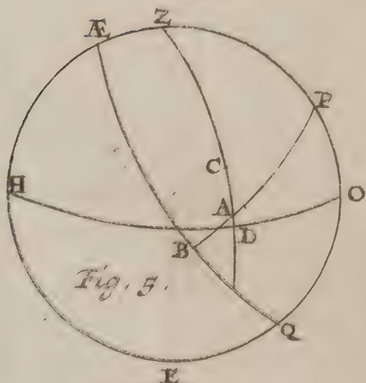


Fig. 5.

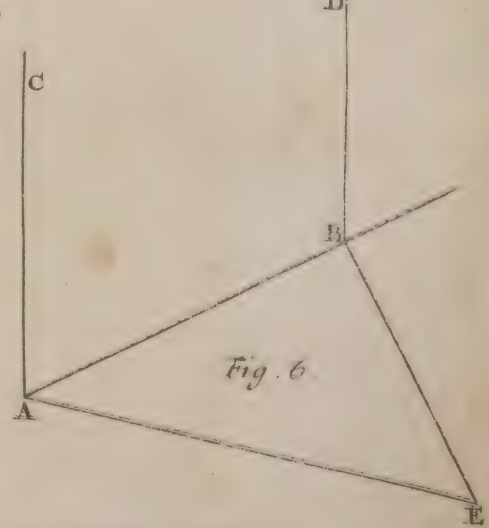


Fig. 6.

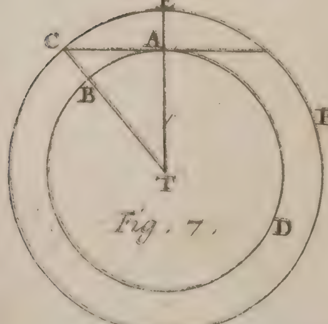


Fig. 7.

we fee the reafon why without hurting our Eyes, we can look upon the Sun at rifing and fetting: But in the Meridian he is not to be looked upon without the danger of hurting our Sight. For the Rays of the Sun in the Horizon penetrating fo large a body of Air, hit againft an infinite number of Particles fwimming in it, and being reflected or abforbed, the force of the Light is thereby much weakned. Since therefore Light is fo much weakned in paffing thro' fo fmall a fpace as our *Atmofphere*; if this *Atmofphere* were fo large as to reach the Moon, and were of the fame Denfity, neither Sun, Moon, nor Stars could then be feen. Lecture XXI.

LECTURE XXI.

Of the Parallaxes of the STARS.

SINCE all the apparent diurnal Motions are performed uniformly round the Axis of the Earth, and not round the place of the Spectator, who lives upon the Earth's Surface; he who obferves the Motion of the *Stars* from this Surface, muft find that they appear to move with a Motion that is not equal. For if a body by its Motion defcribes equally the Periphery of a Circle, the equality of Motion can be feen from no other Points than thofe in the Axis of this Circle. And therefore any *Star* or *Phænomenon* feen from the Center of the Earth will appear in a different Place from what it does when obferved from the Surface; and this difference of Place of the fame *Star*, feen from the Earth's Center and viewed from its Surface, is called the Parallax of that Star.

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Table XX. Fig. 1.

LET A B be a quadrant of a great Circle on the Earth's Surface, where A is the place of the Spectator, and the point V in the Heavens his Vertex or Zenith. Let V N H represent the starry Firmament, the Line A D the sensible Horizon, in which suppose the *Star* C to be seen, whose distance from the Center of the Earth is T C. If this *Star* were observed from the Center T, it would appear in the Firmament in E, and elevated above the Horizon by the Arch D E. This Point E is called the true Place of the *Phænomenon* or *Star*: But an Observer viewing it from the surface of the Earth at A, will observe its Place in the Horizon at D, which is called the visible or apparent Place of the *Star*: And the Arch D E, the distance between the true and visible Place, is named the *Parallax of the* Star.

IF the *Star* rise higher above the Horizon to M, its true Place visible from the Center is P, but its visible Place from the surface is N, and its Parallax is the Arch P N, which is less than the Arch D E. And therefore the horizontal Parallax is greatest of all Parallaxes; and the higher the *Star* rises, the less is its Parallax: And if it should come to the Vertex it would have no Parallax at all. For when it is in Q it is seen both from T and A in the same Line TAV, and there is no difference between its true and visible Place. The further a *Star* is distant from the Earth, so much the less is its Parallax: So the Parallax of the *Star* F is G D; which is less than the Parallax of the nearer *Star* C. Hence it is plain that the Parallax is the Difference of the Distances of a *Star* from the Vertex, when seen from the Center and from the surface of the Earth. For the true distance of the *Star* M from the Vertex is the Arch V P; but when observed from A its visible distance is V N.

THESE distances are measured by the Angles V T M and V A M, contained between the Line V T drawn to the Vertex, and the right Lines T M and A M drawn from the Center and

the

the ſurface of the Earth to the *Star* M: But the difference of theſe two Angles is T M A. For the external Angle V A M is equal to the two inward and oppoſite Angles A T M and A M T: And therefore ATM is the difference of the two Angles VA M and A T M or V T M. This Angle AMT does therefore meaſure the Parallax, and upon that account itſelf is frequently called the Parallax: And this is always the Angle under which the Semidiameter of the Earth AT appears to an Eye placed in the *Star*: And therefore where this Semidiameter is ſeen directly, there the Parallax is greateſt, that is in the Horizon. When the *Star* riſes higher, the Parallax is diminiſhed in the proportion we ſhall ſhew in the following *Theorem.*

THE Sine of the Parallax is to the Sine of the Star's *diſtance from the Vertex in a conſtant and given proportion, which is as the Semidiameter of the Earth to the diſtance of the* Star *from the Earth's Center.*

FOR by a well-known Theorem in *Trigonometry*, in the Triangle A T M, the Sine of the Angle A M T is to the Sine of the Angle TA M or VA M, as A T is to T M; that is in the conſtant proportion of the Semidiameter of the Earth to the *Stars* diſtance. And therefore the Sine of the Parallax in C is to the Sine of the Parallax in M, as the Sine of the Angle VA C is to the Sine of the Angle VA M: And therefore if the Parallax of a *Star* be known when it is at any one diſtance from the Vertex, we can find its Parallax at any other diſtance from the Vertex. If any *Star* or *Phænomenon* be further diſtant from the Earth than 15000 Semidiameters of the Earth, its Parallax will be ſo ſmall that it will be inſenſible and cannot be obſerved: For ſince T F is to TA as 15000 to 1; and as T F is to TA, ſo is the Radius to the Sine of the Angle T F A. Hence we ſhall find the Angle T F A leſs than 14 Seconds, which Angle is ſo ſmall that it cannot be obſerved by any Inſtrument.

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IF we have the diſtance of a *Star* from the Earth, we can eaſily find its Parallax; for in the Triangle TAC rectangular at A, having TA the Semidiameter of the Earth, and TC the diſtance of the *Star*, the Angle ACT, which is the horizontal Parallax, is found by *Trigonometry*: And again, if we have this Parallax we can find the diſtance of the *Star*, for in the ſame Triangle having AT and the Angle ACT we may find out the diſtance TC.

IF a *Star* has no proper Motion of its own, its true diſtance from any Fixed *Star* meaſured by an Arch of a Circle always remains unchangeably the ſame: But if it have a ſenſible Parallax its apparent diſtance will be thereby changed; and if the Fixed *Star* be in the ſame vertical with the *Phænomenon*, but higher than it, the diſtance will appear to grow leſs as it riſes higher. If the *Star* be lower, as they aſcend the diſtance will encreaſe, yet ſeen from the Center they will appear conſtantly to keep the ſame diſtance from each other: And therefore the viſible diſtances of a *Phænomenon* from a Fixed *Star* which is near it, are not the real but apparent ones.

By the Parallaxes the diſtance of a Phænomenon *from the next Fixed Star is conſtantly variable.*

LET there be a *Phænomenon* or *Star* appearing in the Horizon in C: If it were obſerved from the Center, it would be ſeen in Conjunction with the Fix'd *Star* E. But the Spectator in A will ſee it in the ſame Line with the Star D, and will be diſtant from the *Star* E by the Arch DE. But as it riſes higher into M, it will ſtill appear from the Center of the Earth in Conjunction with the ſame *Star* E, which then will appear in P. But from the ſurface of the Earth in A it will appear in N, nearer to the *Star* E than it was when in the Horizon; and therefore will not appear in Conjunction with the ſame *Star* D, as it did before; but will be diſtant from it by the Arch N*d*, making the Arch P*d* equal to ED. Hence it follows, that if any *Phænomenon* always keeps the ſame Poſition in reſpect of the Fixed *Stars*, and changes not its arcual diſtances from them, it has

no

no sensible Parallax. But even likewise if its distance from the *Stars* be changed, yet if that change be only so much as arises from its proper Motion, in that case likewise it will have no sensible Parallax. But if any *Phænomenon* departs further from a Fixed *Star*, or comes nearer to it than what it would do by its proper Motion, this difference of access or recess is the effect of a Parallax.

THE Parallax of a *Star* in a vertical Circle changes its place in regard to the other Circles of the Sphere; and makes its visible Longitude, Latitude, and Right-Ascension to be different from the true ones, which are seen from the Center: And from hence arise four other kinds of Parallaxes.

LET HO be the Horizon, whose Pole is V, EQ the Ecliptick and its Pole P, VA a vertical Circle passing thro' the *Star* whose true Place is C, but apparent Place D, in the same Vertical but nearer to the Horizon; so that the Parallax of Altitude is DC. Thro' the Pole of the Ecliptick and the Star draw the Circle of Latitude PCG, and G will be the true place of the Star reduced to the Ecliptick. But a Circle of Latitude thro' the apparent place D will meet with the Ecliptick in H, which will be the visible or apparent place of the Star in the Ecliptick: The Arch of the Ecliptick GH intercepted between the two Circles of Latitude passing thro' the true and apparent place, is called the Parallax of Longitude, and CN the Parallax of Latitude.

Plate XX. Fig. 2.

The Parallax of Longitude.

IF the Star be in the vertical Circle which cuts the Ecliptick in the 90*th* Degree from the Horizon; *i. e.* in that Vertical which cuts the Ecliptick at Right-Angles; As for Example; In the Point *c* of the Circle VE, the Parallax of Longitude will be nothing. For because the vertical Circle VE is in this case perpendicular to the Ecliptick, it will pass thro' its Poles, and will be the same Circle of Latitude in which is the true and apparent place of the Star; and both these places

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places reduced to the Ecliptick will coincide in the ſame Point: And here the Parallax of Latitude will be the ſame with the Parallax of Altitude.

The Parallax of Latitude.

THE Eaſtern Quadrant of the Ecliptick is that which lyes between the 90*th* Degree and the point of it that riſes: The Weſtern Quadrant lyes between the 90*th* Degree and the ſetting point thereof. A *Star* that is in the Eaſtern Quadrant has its apparent Longitude greater than its true Longitude; for while the *Star* riſes the Parallax depreſſes it towards the *Eaſt*. So in the *Fig.* the viſible place of the *Star* in the Ecliptick is the point H, which is more Eaſterly than the true place G: But if the *Star* be in the Weſtern Quadrant, its viſible Longitude is leſs than the true, becauſe the Parallax thruſts it Weſtward.

LET the Circle E Q, which before repreſented the Ecliptick, be now in the place of the Equator, and P its Pole, P V H the Meridian, V C A a vertical Circle paſſing through the *Star*, in which let C be its true place, and D its apparent. P C G, P D H Secondaries of the Equator or Circles of Declination paſſing thro' the true and apparent Places of the *Star*, meeting with the Equator in G and H. The point G ſhews the true Right Aſcenſion of the *Star*, H its apparent, and the diſtance G H is called the Parallax of Right-Aſcenſion. The true Declination of the *Star* is G C, and its viſible is H D, and their Difference N C is the Parallax of Declination. If a *Star* be to the *Eaſt* of the Meridian, the viſible Right-Aſcenſion is greater than the true; if to the *Weſt* of it, it is leſs: And when the *Star* culminates, the Parallax of Right-Aſcenſion is nothing, becauſe the ſame Circle of Declination does there paſs thro' both the apparent and true place.

THE *Aſtronomers* have invented ſeveral Methods for finding the Parallaxes of *Stars*, that from thence their diſtances from the Earth may be known; for if we knew this, we could make ſome Eſtimate of the Largeneſs and Amplitude of the

the Universe. Let us now give some of the Methods which the *Astronomers* have contrived for searching out the Parallaxes.

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The first way of finding the Parallax.

FIRST observe the *Star* when it is in the same vertical Circle with two other Fixed *Stars*. Let V B be the vertical Circle in which are seen the Fixed *Stars* C and D, and the *Phænomenon* or *Star* S, whose apparent place will be likewise in the same Vertical, which suppose to be E; and if the *Star* have no proper Motion of its own, it will constantly be in the same Line with the two *Stars*: After some time, again observe the Position of the *Phænomenon* with the same *Stars*, when it is not in a vertical Circle with them, but rather in a Circle parallel to the Horizon; *i. e.* Suppose the Fixed *Stars* in *c* and *d*, and let the visible place of the *Star* be *e*; but its true place is in the Line *c d* which joins the two Fixed. It is also in the Vertical V*e*; and therefore it must be in the point where these Lines cut one another, that is in S. Observe the distances of the Fixed *Stars* *d* and *c*, and of the *Star* *e* from the Vertex V: Measure likewise with an Instrument the Arches *de*, *ce* and *dc*: And because *e* is the apparent place of the *Star* and S its true place, the Arch *e* S is its Parallax. In the Triangle *d* V*c* we have all the sides; wherefore we can find the Angle V *d c*: Again in the Triangle V *d e*, we have all the sides, therefore we can find the Angle *d* V *e*. Lastly, In the Triangle *d* V S we have the side *d* V, and the Angles *d* V S and V *d* S, which we found before; therefore we can find the side V S, which being substracted from V *e*, known by Observation, leaves S *e* for the Parallax, which was to be found out.

Plate XX. Fig. 3.

A Second Method.

Plate XX. Fig. 4.

THE Parallax of a *Star* may be likewise easily found this way. Observe when the *Phænomenon* is in any Vertical with a Fixed *Star* which is near it, and then measure its apparent distance from this *Star*: Then observe again when the *Phænomenon* and Fixed *Star* are in equal Altitudes from the Horizon; and then again measure their distance.

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ſtance. The Difference of theſe Diſtances will be very near the Parallax of the *Star.* For let H O be the Horizon, V the Vertex, V E a vertical Circle paſſing through the *Star* in E, and the Fix'd *Star* in D. Let the true place of the *Phænomenon* be S, ſo that S E is the Parallax of Altitude, and the Difference of the *Star's* and the *Phænomenon's* height, is in this caſe their viſible diſtance. Afterwards obſerve when the *Star* and the *Phænomenon* comes to be equally diſtant from the Horizon, and then meaſure their diſtance by an Inſtrument: This viſible diſtance is nearly equal to their true diſtance. For let the true place of the *Phænomenon* be *s*; the Parallax *s e* is very ſmall in compariſon of the Arch V *e*: And therefore *d s* and *d e* will be very near equal; for if the Parallax *s e* were a whole Degree, yet even then *d s* and *d e* would not differ above one Minute: Therefore the diſtance *d e* being meaſured, we ſhall have their true diſtance *d s* or D S, which is greater than D E. And if from D S we ſubſtract DE, known by the firſt Obſervation, there will remain S E the Parallax, which was to be found.

The Third Method.

THE Parallax of a *Phænomenon* may likewiſe be obtained by an Obſervation of its Azimuth and Altitude, and by marking the time between the Obſervation and its arrival at the Meridian. Let H V P O be the Meridian, V the Vertex, P the Pole, H O the Horizon, and V B a vertical Circle paſſing thro' the true and apparent place; thro' which draw alſo Circles of Declination P S C, P E. The Arch of the Horizon B O is the Azimuth of the *Star,* which muſt be obſerved, in the manner we ſhewed in our laſt *Lecture.* Obſerve likewiſe the Arch VE, the diſtance of the *Phænomenon* from the Vertex, and mark the Moment of Time when theſe Obſervations are made. Then ſtay till the *Phænomenon* or *Star* comes to the Meridian, and note the Moment of its arrival there, which may be either done by a Pendulum Clock, or by an Obſervation of a *Star.* Let

Plate XX. Fig. 5.

the

the diſtance of Time between the firſt Obſervation and the ſecond of the *Stars* being in the Meridian, be converted into Degrees and Minutes of the Equator, and we ſhall have the Arch Æ C, which meaſures the Angle V P S. Therefore in the Triangle V P S we have the ſide V P the diſtance of the Vertex from the Pole, and the Angles P V S and V P S; whereby we can find the Arch V S the true diſtance of the *Phænomenon* from the Vertex: This being ſubſtracted from the obſerved diſtance V E, there will remain the Parallax S E, which was to be found.

IT is here to be noted, that for to reduce the Time into Degrees and Minutes of the Equator, that the Time muſt be firſt reduced into Hours and Minutes of the *Primum Mobile*, or to the Time of the Revolution of the Heavens, which Hours are ſomewhat ſhorter than the Solar Hours: Or if you keep the Solar Hours, you muſt reckon for each of them 15 Degrees, 2 Minutes, 27 Seconds, and 51 Thirds: And ſo proportionably for the reſt of the Particles of Time.

A Fourth Method.

SUPPOSE H O an Arch of the Horizon, A M the Meridian, in which P is the Pole, and V the Vertex of the place. Suppoſe E the apparent place of the *Star*; before the *Star* comes to the Meridian obſerve the Arch V E its diſtance from the Vertex, and its Azimuth E V M: Let the true place of the *Star* be S, its Parallax is S E: Mark the time of the Obſervation. Again, after the *Star* has paſſed the Meridian, obſerve when it is exactly at the ſame diſtances from the Vertex, ſo that V *e* may be equal to V E: And here, ſince the viſible diſtances of the *Star* from the Vertex are equal, the real diſtances will be likewiſe equal, *i. e.* V S = V *s*. Take the Time between the firſt and ſecond Obſervation and turn it into Degrees and Minutes of the Equator, and we ſhall have the Angle S P *s*, the half of which is the Angle S P V. Therefore in the Triangle S V P we have the Angle S P V, and the Angle S V P, which is the Complement of the Azimuth to two

Right-

Lecture XXI. Right-Angles; alſo the ſide V P the diſtance of the Pole and Vertex; from them we ſhall know V S the true diſtance of the *Star* from the Vertex, which being ſubſtracted from V E, leaves S E for the Parallax.

The Fifth Method. THESE Practices depend upon Obſervations of the Azimuths; but without obſerving them the Parallax may be known by finding out the apparent and true Right-Aſcenſions, and from them by Calculation finding the Azimuth: For by obſerving the diſtance of a *Phænomenon* from two known Fixed *Stars*, we can compute its apparent Right-Aſcenſion, according to the Method explained in *Lecture* XIX: Then again, when the *Star* comes to the Meridian, by the ſame Method find its Right-Aſcenſion, which is the true Right-Aſcenſion, or the point where the Circle of Declination paſſing thro' the true place of the *Star* cuts the Equator. Knowing then the apparent Right-Aſcenſion of the *Star* in the Vertical V B, and the point of the Equator which at the ſame time culminates, we ſhall likewiſe know the Angle V P E: Therefore in the Triangle V P E having the ſides V P, V E, and the Angle V P E, we can find the Angle P V E, which determines the Azimuth. But having the true Right-Aſcenſion of the *Star* as was obſerved in the Meridian, and the point of the Equator culminating at the firſt Obſervation, the diſtance between them will give us the Angle V P S. Therefore in the Triangle V P S having the two Angles V P S and S P V, as alſo the ſide V P, we can find the ſide V S the real diſtance of the *Star* from the Vertex; which ſubſtracted from V E leaves S E the Parallax, which was to be found.

Plate XXI. Fig. 1.

IN determining the Right-Aſcenſions of the *Stars* we are not to rely too much, in ſo nice an Affair as the Parallax is, on a Pendulum Clock for determining the Time; for there the Error of one Second in numbering being made, will produce an Error of Right-Aſcenſion of 15 Seconds.

FOR to obſerve the Right-Aſcenſion of a *Star*, there is no need of ſtaying till it comes to the Meridian; but it is more eaſily and certainly had by two Obſervations, one made in the Eaſtern Quadrant, and the other in the Weſtern ſide of the Heavens; but both muſt be made when the *Star* is at the ſame height above the Horizon: For if we take the diſtance of the *Phænomenon* from two known Fixed *Stars* when it is in the Eaſtern Region, we ſhall by that means find its apparent Right-Aſcenſion, which is greater than the true, becauſe the Parallax depreſſes a *Star* more Eaſterly. Again, when the *Star* deſcends on the Weſtern ſide, and comes to the ſame height, let its diſtance be likewiſe obſerved from two Fixed *Stars*, and get from them its apparent Right-Aſcenſion, which is juſt as much leſs than the true, as the former exceeded it. And therefore if the Differences between the two apparent Right-Aſcenſions be halfed, and this half be added to the leaſt or ſubſtracted from the greateſt, we ſhall have the true Right-Aſcenſion or the point in the Equator, where it meets with the Circle of Declination paſſing thro' the *Star*, that is the point C. But from the Time of the Obſervation we have the point of the Equator which culminated at that Moment; and conſequently we have the Arch Æ C, and the Angle Æ P C meaſured by it: Therefore in the Triangle V P S, having the ſide V P, and the Angles V P S and P V S, we can find the ſide V S the true diſtance of the *Phænomenon* from the Vertex, which ſubducted from the apparent diſtance, there willremain S E the Parallax required (Table XXI Fig. 5.)

The Sixth Method.

The eaſieſt and beſt way of finding the Parallax of Right-Aſcenſion is by a Teleſcope, in whoſe *Focus* are four Threads croſſing one another at half Right-Angles, as we ſhewed in our XIX*th* *Lecture*. Directing this Teleſcope to the *Star* turn it conſtantly round, till its apparent diurnal Motion appear to be along the Thread A B; in which Poſition the Thread will repreſent a Portion of the Parallel which the *Phænomenon* deſcribes; (Table XXI Fig. 2.)

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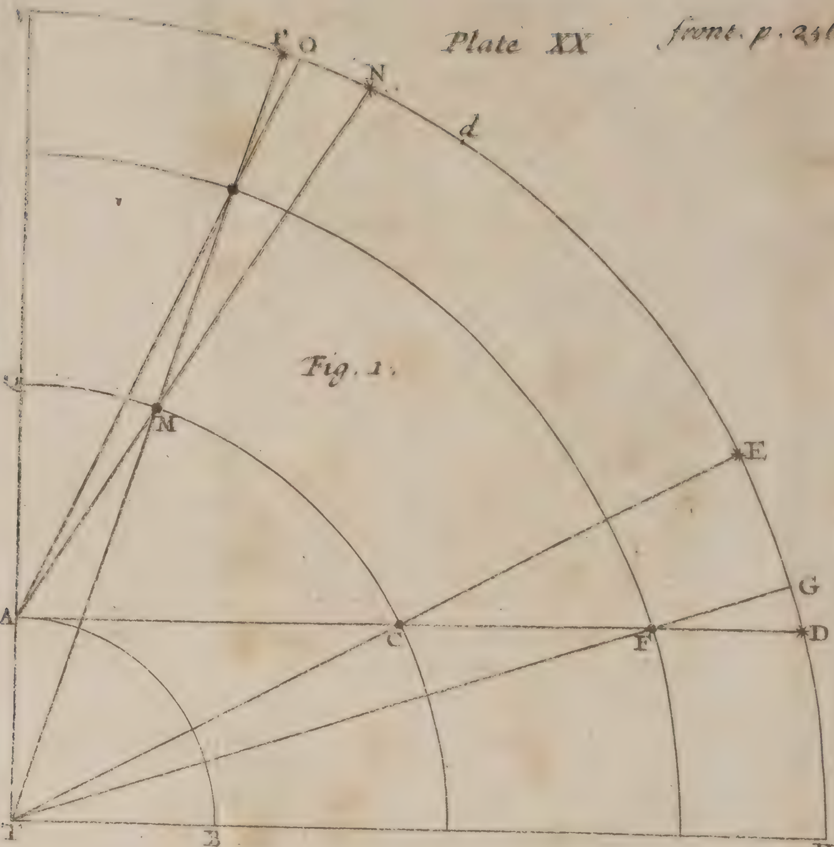
scribes; and the Thread C D cutting it at Right-Angles will represent a Horary Circle. Observe therefore the Time when the *Phænomenon* is seen in the Horary Circle. The Telescope remaining thus fixed and unmoved, observe the Time when any other *Star*, whose Right-Ascension is known, comes to the same Horary Circle: The distance of Time between the Appulse of the *Phænomenon* to the Horary Circle, and of the Fixed *Star* to the same Circle, being turned into Degrees and Minutes of the Equator will shew the Difference of Right-Ascensions of the *Star* and the *Phænomenon*. Again, when the *Star* comes to the Meridian observe it with the Telescope, and by the same Method find out its Right-Ascension, which will be the true one; and by it we shall have the point of the Equator, where the Circle of Declination passing thro' the true place of the *Star* does cut the Equator. Having therefore the true Right-Ascension and the apparent, we have their Difference or the Parallax of Right-Ascension. And because we have the apparent Right-Ascension and the point of the Equator then culminating, we have the Arch of the Equator intercepted between them, which is the measure of the Angle V P E. Therefore in the Triangle V P E we have the sides V P, P E, and the Angle V P E, whence we find the Angle P V E. From the Angle V P E take the Angle S P E the Parallax of Right-Ascension, and we shall have the Angle V P S. Lastly, In the Triangle V P S, having the Angles V P S and P V S, together with the side V P, we can from them find the side V S, the true distance of the *Star* from the Vertex, which being subducted from the apparent distance, leaves the Parallax that was to be found.

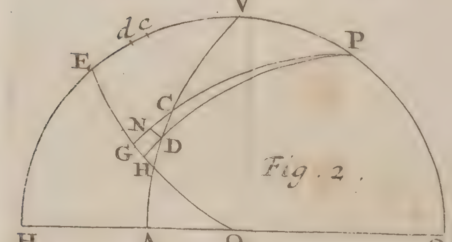
Table XXI. Fig. 1.

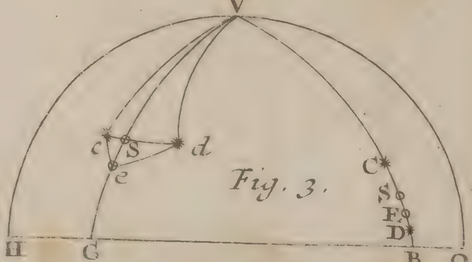
The Method of finding the Parallax when the Star *has a proper Motion of its own.*

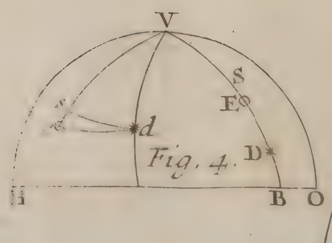
IF the *Phænomenon* have a proper Motion of its own, its Right-Ascension will constantly be changed by this Motion, unless it should happen to move in some Circle of Declination: And therefore Care must be taken to determine the Change of Right-Ascension that arises by the Motion of the *Star*; which is done by observing the

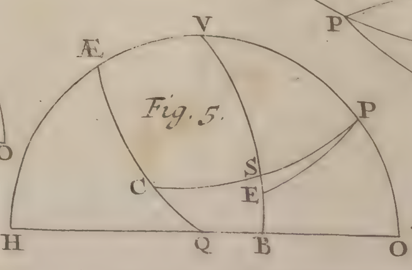
Plate XX *front. p. 246*

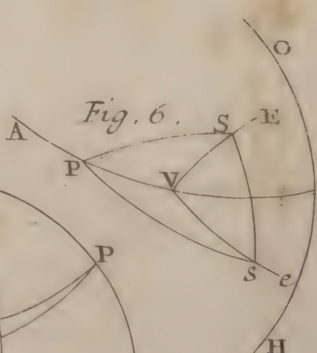












the Right-Aſcenſion of the *Star* when it is in the Meridian; and the next Day let its Right-Aſcenſion be in the ſame manner obſerved. The Difference of theſe Right-Aſcenſions will ſhew the Change that the Right-Aſcenſion has, for the Time between the two Obſervations: And from them we can find the Change of Right-Aſcenſion or the Motion of the *Phænomenon* along the Equator in a Day: From this diurnal Motion we can find by proportioning the Motion for any given Time. For Example, If the diurnal Motion according to the Equator be 30 Min. that is, ſuppoſe the *Phænomenon* advanced according to the Equator every Day 30 Minutes: And ſuppoſe the Time between the Obſervation on the Eaſtern ſide of the Heaven, and that in the Meridian be ſix Hours, the Motion according to the Equator in that time is $7\frac{1}{2}$ Minutes; let the Difference of Right-Aſcenſion obſerved in the Vertical and in the Meridian be 20 Minutes, Seven and a half of thoſe Minutes are owing to the proper Motion of the Body; wherefore the Parallax of Right-Aſcenſion is $12\frac{1}{2}$ Minutes.

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AFTER the ſame manner by the apparent and real Longitude of a *Phænomenon* the Parallaxes may be inveſtigated. The apparent Longitude is found by obſerving the diſtance of a *Phænomenon* from two Fixed *Stars* whoſe Longitudes and Latitudes are known. And the true Longitude is had by making the ſame Obſervations when the *Star* is in the 90*th* Degree of the Eclíptick, where the apparent and true Longitudes coincide.

BY theſe and the like Methods if any *Phænomenon* has a Parallax not leſs than one Minute it may be found out. In the Moon we find the Parallax very conſiderable, which in the Horizon amounts to about a Degree or more. But there are ſome particular Methods only applicable to the Moon, by which its Parallax is known.

A Method for obſerving the Parallax of the Moon.

IN an Eclipſe of the Moon obſerve when both its Horns are in the ſame vertical Circle, and then in that Moment take the Altitudes of both

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Horns: The Difference of these two Altitudes being halfed and added to the least, or substracted from the greatest, does give nearly the visible Altitude of the Moon's Center: But the true Altitude is nearly equal to the Altitude of the Center of the Shadow at that time. Now we know the Altitude of the Center of the Shadow, because we know the place of the Sun in the Ecliptick, and its Depression under the Horizon, which is equal to the Altitude of the opposite point of the Eclipitck, in which is the Center of the Shadow. And therefore we have the true Altitude of the Moon and the apparent Altitude, whose difference is the Parallax, which will therefore be known.

Tables of the Moon's Parallaxes.

AS the distance of the Moon grows less, according as it recedes from its *Apogæum* her Parallax must in the same proportion be encreased, constantly the nearer she comes to us. Therefore the Artists make Tables which shew the horizontal Parallax for every Degree of its Anomaly.

THE Methods we have given for finding the Parallaxes shew that the Moon has a great Parallax, and is very near us; but none of them is sufficient for finding out the Parallax of the Sun: For that is so small, that the Observations requisite cannot be made accurately enough for to determine it; for an Error in observing can scarcely be avoided, which is not equal or greater than the Sun's Parallax. This defect of Observations put the Antient *Astronomers* on the search of other Methods peculiar to the Sun for finding out its Parallax: But even those Methods, though they make manifest the Acuteness and Sagacity of the Antients, yet are not sufficient in so nice and subtle a Disquisition. However, they are useful to shew that the distance of the Sun from the Earth is very great in comparison of the Moon's distance from the same: And therefore it will not be unfitting to explain them in this place.

Hipparchus's *Method for the Parallax of the Sun.*

THE first Method was invented by *Hipparchus*, and has been made use of by *Ptolemy* and his Followers, and many other *Astronomers*. It depends

depends on an Obſervation of an Eclipſe of the Moon: And the Principles on which it is founded are, *Firſt*, In a Lunar Eclipſe the horizontal Parallax of the Sun is equal to the difference between the apparent Semidiameter of the Sun and half the Angle of the Conical Shadow; which is eaſily made out in this manner. Let the Circle A F G repreſent the Sun and D H E the *Earth*; let D H M be the Shadow and D M C the half Angle of the Cone. Draw from the Center of the Sun the Right-Line S D touching the Earth, and the Angle D S C is the apparent Semidiameter of the Earth ſeen from the Sun, which is equal to the horizontal Parallax of the Sun; the Angle A D S is the apparent Semidiameter of the Sun ſeen from the Earth: The external Angle A D S is equal to the two internals D M S and D S M, by the 32*d* *Prop*. Elem. I. And therefore the Angle D S M or D S C is equal to the Difference of the Angles A D S and D M S. 2*dly*, Half the Angle of the Cone is equal to the difference of the horizontal Parallax of the Moon and the apparent Semidiameter of the Shadow, ſeen from the Earth at the diſtance of the Moon. For let CDE be the Earth, C M E the Shadow, which at the diſtance of the Moon being cut by a Plane, the Section will be the Circle F L H, whoſe Semidiameter is F G, and is ſeen from the Center of the Earth under the Angle F T G. But by the 32*d* *Prop.* Elem. I. the Angle C F T is equal to the two internals F M T, and F T M. Wherefore the Angle F M T is the difference of the two Angles C F T and G T F: But the Angle C F T is the Angle under which the Semidiameter of the Earth is ſeen from the Moon, and this is equal to the horizontal Parallax of the Moon; and the Angle G T F is the apparent Semidiameter of the Shadow ſeen from the Earth's Center. It is therefore evident that the half Angle of the Cone is equal to the difference of the horizontal Parallax of the Moon and the apparent Semidiameter of the Shadow ſeen from the Earth. Wherefore if to the apparent Semidiameter of the Sun

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Plate XXI. Fig. 3.

Plate XXI. Fig. 4.

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Sun there be added the apparent Semidiameter of the Shadow, and from the sum you take away the horizontal Parallax of the Moon, there will remain the horizontal Parallax of the Sun; which therefore if these were accurately known, would be likewise known accurately: But none of them can be so exactly and nicely obtained as to be sufficient for determining the Parallax of the Sun; for very small Errors which cannot be easily avoided in measuring these Angles, will produce very great Errors in the Parallax; and there will be a prodigious difference in the distances of the Sun when drawn from these Parallaxes. For Example, Suppose the horizontal Parallax of the Moon to be 60′. 15″, the Semidiameter of the Sun 16′, and the Semidiameter of the Shadow 44′. 30″; we should conclude from thence that the Parallax of the Sun was 15″, and his distance from the Earth about 13700 Semidiameters of the Earth. But if there be an Error committed, in determining the Semidiameter of the Shadow, of 12″ in defect, (and certainly the Semidiameter of the Shadow cannot be had so precisely as not to be liable to such an Error) that is, if instead of 44′. 30″ we put 44′. 18″ for the apparent Diameter of the Shadow, all the others remaining as before, we shall have the Parallax of the Sun 3″, and its distance from the Earth almost 70000 Semidiameters of the Earth, which is five Times more than what it was by the first Position. But if the fault were in excess, or the Diameter of the Shadow exceeded the true by 12″; so that we should put it 44′. 42″, the Parallax would arise to 27″, and the distance of the Sun only 7700 of the Earth's Semidiameter; which is nine times less than what it comes to by a like Error in defect. If an Error in defect was committed of 15″, which is still but a small Mistake, the Sun's Parallax would be equal to nothing, and his distance infinite. Wherefore since from so small Mistakes the Parallax and distance of the Sun vary so much, it is plain that the distance of the Sun cannot be obtained by this Method.

Hipparchus's Method insufficient.

SINCE

SINCE therefore the Angle that the Earth's Semidiameter ſubtends at the Sun is ſo ſmall, that it cannot be determined by any Obſervation; *Ariſtarchus Samius*, an Antient and great *Philoſopher* and *Aſtronomer*, contrived a very ingenious way for finding the Angle which the Semidiameter of the Moon's Orbit ſubtends when ſeen from the Sun: This Angle is about ſixty times bigger than the former ſubtended only by the Earth's Semidiameter. For to find this Angle, he lays down the following Principles.

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Ariſtarchus's *Method for the Sun's diſtance.*

IN that *Lecture* where we explained the *Phaſes* of the Moon, we ſhewed that if a Plane paſſed thro' the Moon's Center, to which the Line joyning the Sun and Moon's Center was perpendicular, this Plane would divide the illuminated Hemiſphere of the Moon from the dark one: And therefore if this Plane ſhould likewiſe paſs thro' the Eye of a Spectator on the Earth, the Moon would appear biſected or like a half Circle; and a Right Line drawn from the Earth to the Center of the Moon would be in the Plane of Illumination, and conſequently would be perpendicular to the Right-Line which joins the Centers of the Sun and Moon. Let S be the Sun and T the Earth, A L *q* a Quadrant of the Moon's Orbit; and let the Line S L drawn from the Sun touch the Orbit of the Moon in L; the Angle T L S will be a Right-Angle: And therefore when the Moon is ſeen in L it will appear biſected or juſt half a Circle. At the ſame time take the Angle L T S the Elongation of the Moon from the Sun, and then we ſhall have the Angle L S T its Complement to a Right-Angle. But we have the ſide T L, by which we can find the ſide S T, the diſtance of the Sun from the Earth.

Table XXI. Fig. 5.

BUT the difficult point is to determine exactly the Moment of Time when the Moon is biſected, or in its true *Dichotomy*; for there is a conſiderable ſpace of Time both before and after the *Dichotomy*; nay, even in the Quadrature, when the Moon will appear biſected or half a Circle;

Ariſtarchus's *Method inſufficient.*

Lecture XXI. ſo that the exact Moment of Biſection cannot be known by Obſervation, as Experience tells us: This can be alſo made out by the following reaſon. In the *Lecture* concerning the *Phaſes* of the Moon, it was demonſtrated that the Diameter of the Earth was to the Portion of it illuſtrated by the Sun, and ſeen by us, as the Diameter of a Circle is to the *Verſed Sine* of the Elongation of the Moon from the Sun, nearly: But accurately it is as the Diameter of a Circle to the *Verſed Sine* of the exterior Angle at the Moon, of the Triangle formed by Lines joining the Centers of the Sun, Earth and Moon, as we ſhewed in the *Lecture* concerning the *Phaſes* of *Venus*. Let us ſuppoſe in the time of true *Dichotomy* or Biſection, that the Angle L S T is 15′, and that the Semidiameter of the Lunar Orbit were 60 Semidiameters of the Earth; the diſtance of the Sun would in that Caſe be 13758 of the Earth's Semidiameters. This being ſuppoſed, let us imagine the Moon to be in her Quadrature at *q*; that is, let the Angle *q* T S be a Right-Angle, the exterior Angle of the Triangle *q* T S at *q* would be 90°. 15′, whoſe *Verſed Sine* is equal to the Radius and the Right Sine of 15′ together: Therefore as the Diameter of a Circle is to the Radius + Sine 15′; ſo is the Diameter of the Moon to that part of it which is illuſtrated by the Sun, and ſeen from the Earth. Wherefore taking half the Antecedents, and by Diviſion of Ratio, the Radius will be to the Right Sine of 15′, as is the Semidiameter of the Moon to that exceſs, wherewith the illuminated part ſeen from the Earth is greater than half the Moon's Diameter. Now the Sine of 15′ is 436, of ſuch parts as the Radius is 100000, and the apparent Semidiameter of the Moon is about 15′: Say therefore, as 100000 is to 436, ſo is 15′ to a fourth, which is leſs than 4″; but this is ſo ſmall a Quantity, that it is not in the leaſt to be perceived by our Senſes: And therefore the Moon, even in the Quadratures, has its Illumination exceeding the biſected Illumination by ſuch a quantity

tity as is altogether imperceptible: But if the real *Dichotomy* or Bisection were in the Quadrature, the distance of the Sun would be in Infinite; for in that case the Angles S T q and S q T being right, the Lines S T and S q would be parallel, and would not meet but at an infinite distance. Lecture XXI.

2*dly*, SUPPOSE the Elongation of the Moon from the Sun 89°. 30′: In that case the exterior Angle at the Moon is 89°. 45′, and its *Versed Sine* equal to the Radius bating the Right Sine of 15′. And because as the Radius is to the *Versed Sine* of the exterior Angle, that is, to the Radius diminished by the Sine of 15′; so is the Semidiameter of the Moon to that part of it which is illustrated and seen by us; then by Division of *Ratio*, the Radius will be to the Sine of 15′; as is the Moon's Semidiameter to that part whereby the Semidiameter of the Moon is greater than the illuminated part thereof which is seen by us; which therefore (as in the former Case) will be scarce 4″: Now the Moon wanting but so small a portion to be intirely bisected, will appear to us as if she were really bisected; so that its *Phasis* can in no wise be distinguished from the true *Phasis* of a *Dichotomy*: And therefore if this apparent *Phasis* should be taken for the true *Phasis* of the *Dichotomy*, which is half a Degree distant from the Quadrature, we should find the distance of the Sun from us to be 6876 Semidiameters of the Earth.

OBSERVATIONS inform us, that when the Moon is 30 Min. distant from the Quadratures it appears bisected; and in the Quadrature its *Phasis* cannot be perceived to be different from a bisected *Phasis*: Nay, the Moon observed with the best Telescopes, after it has past the Quadratures, appears bisected, as *Ricciolus* himself acknowledges in his *Almægest*, p. 734. And therefore the Moon, at least for the space of one Hour, appears to be bisected, in which time any Moment may be taken for the true point of the *Dichotomy*, as

Lecture XXI. well as any other: And for the infinite Number of Moments of Time, we ſhall have an infinite diverſity of Diſtances of the Sun from the Earth: And conſequently the true diſtance of the Sun from the Earth cannot be obtained by this Method.

SINCE the Moment in which the true *Dichotomy* happens is uncertain, but it is certain that it happens before the Quadrature; *Ricciolus* takes that point of Time which is in the middle, between the Time that the *Phaſis* begins to be doubtful whether it be biſected or not, and the Time of Quadrature: But he had done righter, if he had taken the middle point between the Time, when it becomes doubtful whether the Moon's ſide is concave or ſtreight, and the Time again when it is doubtful whether it is ſtreight or convex; which point of Time is after the Quadrature: And if he had done this, he would have found the Sun's diſtance a great deal bigger than he has made it.

There is no need to confine this Method to the Phaſis of a Biſection.

THERE is now no need to confine this Method to the *Phaſis* of a *Dichotomy* or Biſection, for it can be as well perform'd when the Moon has any other *Phaſis* bigger or leſs than a *Dichotomy*: For obſerve by a very good Teleſcope with a Micrometer the *Phaſis* of the Moon, that is, the proportion of the illuminated part of the Diameter to the whole; and at the ſame Moment of Time take her Elongation from the Sun: The illuſtrated part of the Diameter, if it be leſs than the Semidiameter, is to be ſubducted from the Semidiameter; but if it be greater, the Semidiameter is to be ſubducted from it, and mark the reſidue: Then ſay, as the Semidiameter of the Moon is to the reſidue, ſo is the Radius to the Sine of an Angle, which is therefore found: This Angle added to, or ſubſtracted from a Right-Angle, gives the exterior Angle of the Triangle at the Moon: But we have the Angle at the Earth, which is the Elongation obſerved; which therefore being ſubducted from the exterior Angle, leaves the Angle

at the Sun. And in the Triangle S L T, having all the Angles and one ſide L T, we can find the other ſide S T, the diſtance of the Sun from the Earth. But it is almoſt impoſſible to determine accurately the Quantity of the Lunar *Phaſis*, ſo that there may not be an Error of a few Seconds committed; and conſequently we cannot by this Method find preciſely enough the true diſtance of the Sun. However, from ſuch Obſervations we are ſure that the Sun is above 7000 Semidiameters of the Earth diſtant from us. Since therefore the true diſtance of the Sun can neither be found by Eclipſes, nor by the *Phaſes* of the Moon, the *Aſtronomers* are forced to have recourſe to the Parallaxes of the Planets that are next to us, as *Mars* and *Venus*, that are ſometimes much nearer to us than the Sun is: Their Parallaxes they endeavour to find by ſome of the Methods above explained: And if theſe Parallaxes were known, then the Parallax and diſtance of the Sun, which cannot directly by any Obſervations be attained, would eaſily be deduced from them. For from the Theory of the Motions of the Earth and Planets, we know at any time the proportion of the diſtances of the Sun and Planets from us; and the horizontal Parallaxes are in a reciprocal Proportion to theſe diſtances. Wherefore knowing the Parallax of a Planet, we may from thence find the Parallax of the Sun.

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The Sun's diſtance and Parallax may be deduced from the Parallax of the Planets.

MARS, when he is an Acronychal Poſition, that is, oppoſite to the Sun, is twice as near to us as the Sun is; and therefore his Parallax will be twice as great. But *Venus* when ſhe is in her inferior Conjunction with the Sun, is four-times nearer to us than he is, and her Parallax is greater in the ſame proportion: Therefore, tho' the extream ſmalneſs of the Sun's Parallax renders it unobſervable by our Senſes, yet the Parallaxes of *Mars* or *Venus* which are twice or four-times greater, may become ſenſible. The *Aſtronomers* have beſtowed much Pains in finding out the Parallax of *Mars*; but of late *Mars* was in his Oppoſition

Particularly by Mars *in an Acronychal Poſition.*

to

Lecture XXI. to the Sun, and alſo in his *Perihelion*, and conſequently in his neareſt approach to the Earth: And then he was moſt accurately obſerv'd by two of the moſt eminent *Aſtronomers* of our Age; who have determined his Parallax to have been ſcarce 30 Seconds; from whence we can eaſily collect that the Parallax of the Sun is ſcarce 11 Seconds, and his diſtance about 19000 Semidiameters of the Earth.

The Parallax of the Sun found by obſerving Venus *in the body of the Sun.*

BY an Obſervation of the Body of *Venus* ſeen paſſing over the Body of the Sun, which will happen in *May* 1761, Dr. *Halley* has ſhewed a Method of finding the Parallax and Diſtance of the Sun to a great nicety, *viz.* within a five hundredth part of the whole; and we muſt wait till then before it can be determin'd to ſo great an exactneſs.

BECAUSE the Method whereby the *Aſtronomers* foretel Eclipſes of the Sun requires that the Moon's Parallax both as to Longitude and Latitude ſhould be known by Calculation: And alſo as often as the Moon's place in the Heavens is to be obſerved, that it may be compared to the place found out by *Aſtronomical* Tables, in order to eſtabliſh her Theory, it will be neceſſary to reduce the true place found by the Tables to her apparent place, which cannot be done without the Calculation of the Parallax: It will be convenient to explain the Method by which the Moon's Parallax for any point of Time is to be calculated.

How the Moon's Parallax is to be found for any time by Calculation.

FIRST, by *Aſtronomical* Tables compute the place of the Moon in the Ecliptick and her Latitude, for the given Time. In the Figure ſuppoſe H O the Horizon, H Z O the Meridian, Z the Vertex, E C the Ecliptick, in which let L be the place of the Moon, found by the Tables. And firſt, let us ſuppoſe the Moon to be without Latitude. From the Vertex Z let fall upon the Ecliptick the perpendicular Z *n* A, which will be therefore a Circle of Latitude; And the point *n* will be the 90*th* Degree of the Ecliptick. From the Time given we have the Right-Aſcenſion of the

Table XXI. Fig. 6.

Sun,

Sun, and his Equatorial distance from the Meridian: From thence we shall find the point of the Equator culminating, which is the Right-Ascension of Mid-Heaven, or of that point of the Ecliptick which culminates: And therefore we know that point which is then in the Meridian, as also the Angle Z E N of the Ecliptick and Meridian. This is either found by the Calculation we explained in the spherical Doctrine, or by Tables of *Astronomy*: By this means we find the Arch E L; but we have the Arch E Æ the Declination of the point E, and consequently the Arch Z E will be known. Therefore in the Right-angled Triangle Z *n* E, we have the side Z E and the Angle Z E *n*. Hence we can find E *n* and the point *n*, or the point of the 90*th* Degree, and the Arch Z *n* its distance from the Vertex; whose Complement *n* A is the measure of the Angle that the Horizon and the Ecliptick make: And because we have the place of the Moon we must have the Arch *n* L. Therefore in the Right-angled Triangle Z *n* L, having the sides Z *n* and *n* L, we shall have from them the Angle Z L *n*, which is called the *Parallactick Angle*, as likewise the side Z L, the distance of the Moon from the Vertex. Let the Radius be to the Sine of the Arch Z L, as the horizontal Parallax of the Moon taken from the Tables to its Parallax in L, which therefore is found. Let it be *o* L. From *o* on the Ecliptick let fall the Perpendicular *o m*. And in the Triangle *o* L *m* (which being very small, may be taken for a rectilinear one) we have besides the Right-Angle, the side L *o* and the Angle *o* L *m* equal to Z L *n*; wherefore we shall find out the Arch L *m* the Parallax of Longitude, and *o m* the Parallax of Latitude, which were to be found.

Lecture XXI.

The Parallactick Angle.

SUPPOSE now the Moon has some Latitude, and its place in the Ecliptick be the point L, but let it be placed in the Circle of Latitude L P at P. And because the Angle *n* L P is right, and we have the Angle *n* L Z and its Complement

Lecture XXI. ment Z L P; In the Triangle Z L P we have two ſides, Z L which was found before, and L P the Moon's Latitude, and the Angle Z L P, whereby we can find out the ſide Z P, and the Angle Z P L. Let the Radius be to the Sine of the Arch Z P, as the horizontal Parallax of the Moon to a fourth, which will be P *q*: This will be the Parallax of the Moon in the Circle of Altitude. Let *q d* be an Arch parallel to the Ecliptick; and in the ſmall Triangle P *d q*, which may be taken as a Right-angled Triangle, we have the Angle *d* P *q*, which is the Complement of the Angle Z P L to two Right-Angles, and the ſide P *q*: Therefore we ſhall have P *d* the Parallax of Latitude, and *q d* the Parallax of Longitude: For becauſe the Latitude of the Moon is but ſmall, the Arch of the Parallel *d q* is nearly equal to the Arch of the Ecliptick which is correſpondent to it.

LECTURE XXII.

The Theory of the Annual Motion of the EARTH.

HITHERTO we have given an Account of the general Affections of the Planets Motions, and have explained the Appearances which ariſe from their Motions and the Motions of the *Earth* together. We will now come to their particular Theories, in which the Period of each, its Diſtance from the Sun, the Form of its Orbit, and its Poſition are determined; which being once known,

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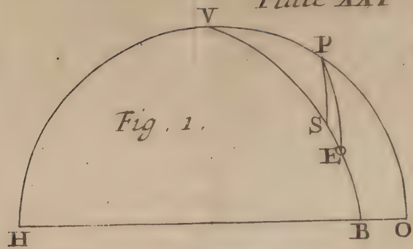
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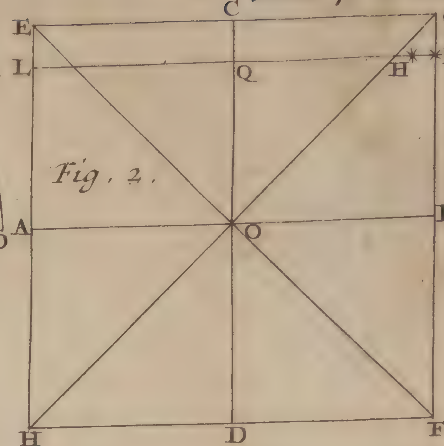
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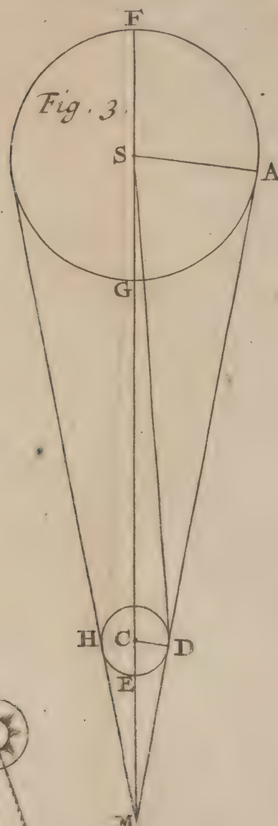
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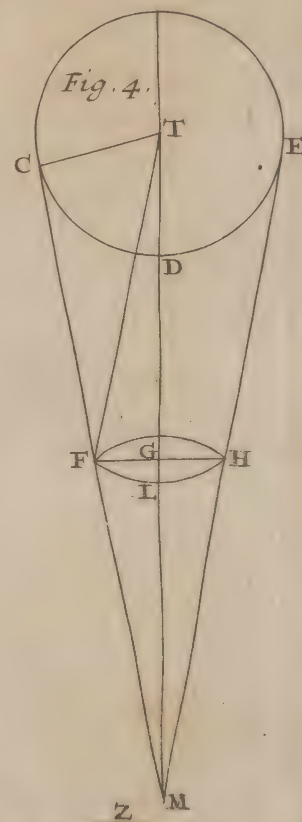
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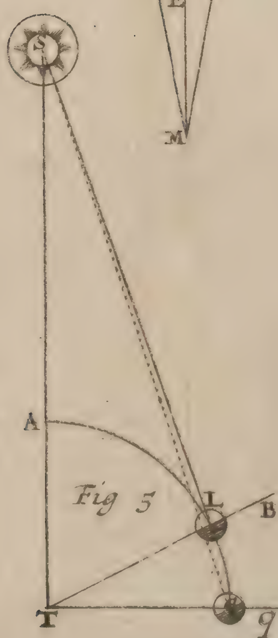
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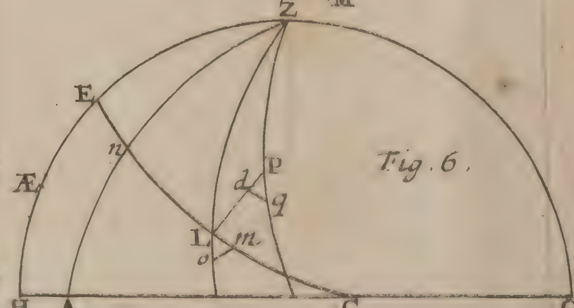
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known, the Place of any Planet in the *Zodiack* may be computed for any given Time. And because the Theories of the Planets are founded on the Motion of the *Earth*, and are investigated by this Motion, it will be necessary to begin with the Theory of the *Earth*.

Lecture XXII.

IN our VIIth *Lecture* we shewed how the Motion of the *Earth* round the Sun was the cause of the Appearance of the annual Motion of the Sun in the Ecliptick; and that the Sun observed from the *Earth* seemed to describe the same Circle in the Heavens, that a Spectator in the Sun would see the *Earth* really to move in. But the place of the *Earth* seen out of the Sun is always diametrically opposite to that point of the Ecliptick in which we on the *Earth* observe the Sun to be placed: And therefore when the Sun appears to us in ♈, the *Earth* is really in ♎; when he is in ♋, the *Earth* has its Mansion in ♑. And therefore from the apparent place of the Sun, which we find out by Observation, we can easily determine the place of the Earth in its proper Orbit.

The Motion of the Earth *found by observing the Motion of the Sun.*

SINCE the Ecliptick cuts the Equator in two opposite Points, the Sun will twice every Year appear in the Equator or Equinoctial Circle, which happens when by his apparent Motion he arrives at the Intersections of these two Circles: All the rest of the Year he will seem to decline either to the North or South from the Equator; and he is at his farthest distance from the Equator when he is just in the middle between the two Sections, that is, 90 Degrees removed from either, and there the Sun does not seem to alter his Declination for some time; and then the Days keep the same length: And therefore these points which are the first of ♋ and ♑ are called the *Solstitial Points*, as the Intersection of the Equator and Ecliptick are called the *Equinoctial Points*, because when the Sun is seen in them the Days and Nights are equal.

The Sun is twice every Year in the Equinoctial Circle.

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SINCE the Sun is ſeen continually moving in the Ecliptick, and every Day ſeems to advance a Degree Eaſtward, he makes no ſtay in the Equinoctial Points; but in paſſing on, in the ſame Moment he arrives there he leaves them: And therefore tho' the Day the Sun enters the Equinoctial point is called the *Equinox*, becauſe it is reputed equal to the Night; yet it is not preciſely ſo, unleſs the Sun enters the Equator at Mid-Day. For if the riſing Sun ſhould enter the Vernal Equinox, at ſetting he will have departed from it, and decline Northwards about the ſpace of 12′; and therefore that Day will be ſomewhat longer than 12 Hours, and the Night ſhorter; but the Difference is ſo ſmall that it may be neglected in this matter.

The Inveſtigation of the Sun's entring the Equator.

THE moment of Time in which the Sun enters the Equator is found out by Obſervation, and from the Latitude of the place of the Obſerver. For in the Equinoctial Day or near it, with an Inſtrument exactly divided into Degrees, Minutes and parts of Minutes, take the Meridian Altitude of the Sun: If it be equal to the Altitude of the Equator, or to the Complement of the Latitude, the Sun is in that very Moment in the Equator; but if it is not equal take the Difference and mark it, for it will be the Declination of the Sun. Then the next Day again obſerve the Meridian Altitude of the Sun, and gather from thence his Declination. If theſe two Declinations be of different kinds, as the one South and the other North, the Equinox happens ſome time between the two Obſervations, or if they be both of the ſame ſort, the Sun has either not entered the Equinoctial, or has paſt it. And from theſe two Obſervations of the Sun's Declination the Moment of the Equinox is thus inveſtigated.

Table XXII. Fig. 1.

LET CAB be a portion of the Ecliptick, Æ A Q an Arch of the Equator, and let their Interſection be in A. Let C Æ be the Declination of the Sun at the time of the firſt Obſervation, E D his

his Declination in the ſecond Obſervation, the Arch C E will be the Motion of the Sun in the Ecliptick for one Day. In the ſpherical Triangle A Æ C Right-angled at Æ, we have the Angle A which the Equator and the Ecliptick make, which we ſhewed how to find out in *Lecture* XIX; as alſo C Æ the Declination of the Sun known by Obſervation, by which we ſhall find the Arch C A. And in the ſame manner in the Triangle A E D the ſide A E is found, and thence the Arch C E, which is the Sum or Difference of the Arches C A, A E. Say then as C E is to C A, ſo is 24 Hours to the time between the firſt Obſervation and the Moment of the Ingreſs of the Sun to the Equinox.

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The quantity of the Tropical Year.

IF again the next Year the time of the Sun's Entry in the Equator be obſerved in the ſame manner, the Time elapſed between the two Ingreſſes is the ſpace of a *Tropical Year*, or the Time wherein the Sun or rather the *Earth* compleats its Courſe in the Ecliptick; which is called the *Tropical Year*, becauſe after it is finiſhed, all the Seaſons return again in the ſame Order. But by Obſervations that are made at the diſtance of a Year, we cannot ſafely rely upon the true quantity of the Year collected from them; for a ſmall Error of one Minute being conſtantly encreaſed and multiplied by the Number of Years, in proceſs of Time would amount to a prodigious miſtake in the place of the Sun. Therefore the *Aſtronomers* more accurately determine the quantity of the Year, by taking the Obſervations of two Equinocties at many Years diſtance from one another, and dividing the Time between the Obſervations by the number of Revolutions the Sun has made; the Quotient will ſhew the time of one Revolution, or nearly the Period of the *Earth* in her Orbit. For by this means, if there be any miſtake made in the Obſervation, it will be divided into ſo many parts, according to the number of Years, that it will be inſenſible for the ſpace of one Year.

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The Anomalistical Year.

THE space of Time belonging to the *Tropical Year* is by this means found to consist of 365 Days, 5 Hours, 48 Minutes and 57 Seconds. This Time is somewhat less than the Periodical Time of the *Earth* in her Orbit, which is called the *Anomalistical* or *Periodical Year.* For by reason of the Præcession of the Equinoctes, which was explained by us in the VIIIth *Lecture*, by which the Points of Intersection do constantly every Year move back 50 Seconds, and as it were meet the Sun; the Sun will arrive at the Intersection before he has compleated his Course. Now the Time of the *Earth*'s Period or *Anomalistical Year* is 365 Days, 6 Hours, 9 Minutes and 14 Seconds.

The Motion of the Sun in the Ecliptick unequal.

IF the Motion of the *Earth* round the Sun were equal, that is, if it described equal Angles round the Sun in equal times, the apparent Motion of the Sun in the Ecliptick would always be equal, and would proceed each Day in the Ecliptick 59′. 8″.: And therefore the place of the Sun would easily be computed for any Time. But we are sure by Observation that the apparent Motion of the Sun is not equal, and that he goes thro' some parts of the Ecliptick quicker than thro' others; and particularly in going thro' the Northern Semicircle of the Ecliptick, he spends near eight Days more than in passing over the Southern Semicircle, which ought to be performed precisely in the same time, if the apparent Motion of the Sun were equal. Moreover, if we make Observations, and from them find out the Motion of the Sun in the Ecliptick for each Day; in some Days he will be found to move thro' the space of 61 Minutes in a Day; at other times he will scarcely be seen to have compleated 57 Minutes.

THE daily Motion of the Sun in the Ecliptick is observed in this manner. Let CB represent the Ecliptick, ÆQ the Equator, whose common Intersection is in A: Take with an Instrument the Meridian Altitude of the Sun; the Altitude of the

the Equator in the place of Obſervation is likewiſe to be known: The difference of theſe two Arches is the Declination of the Sun, which will therefore be known. Let G be the place of the Sun in the Ecliptick, and F G his Declination. In the Right-angled Triangle G F A, having the ſide F G and the Angle A, we ſhall find the Arch A G the diſtance of the Sun from the Equinoctial point, or his Longitude and Place in the Ecliptick at the time of the Obſervation. The next Day again obſerve the Meridian Altitude of the Sun, and find from thence his Declination, which ſuppoſe to be M L, from which and the Angle A, by the ſame Method, we ſhall find out the Arch M A; from which ſubſtract the Arch A G, and we ſhall have the Arch G M, which is paſſed thro' by the Sun in one Day. The bigneſs of this Arch is mutable, according to the place the *Earth* has in its Orbit.

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The circular Hypotheſis of the Antients by which they explain'd the Appearances.

THE Antient *Aſtronomers*, who allowed no Motions in the Heavens but what were circular and equal, that they might give an account of this apparent Inequality of the Sun's Motion, imagined that the Sun moved round the *Earth* or the *Earth* round the Sun (for it is the ſame thing which we ſuppoſe to move or ſtand ſtill) in a circular Orbit, but Eccentrical; that is, whoſe Center was at ſome diſtance from the Center of the Ecliptick, in which they placed either the Sun or the *Earth*; and this circular Orbit they ſuppoſed was deſcrib'd by an equal Motion: And therefore becauſe the Center of the Ecliptick was at ſome diſtance from the Center of equal Motion, the Motion of either the Sun or *Earth* ſeen from the Center of the Ecliptick would appear unequal.

Table XXIII. Fig. 2.

LET the Circle ♈ ♋ ♎ ♑ repreſent the Ecliptick, in whoſe Center is the Sun, M P N A the Orbit of the *Earth* whoſe Center is C, diſtant from the Center of the Ecliptick by the Line C S, which is called the Eccentricity. They ſuppoſed the *Earth* to move in this Circle with an equal

 Motion;

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Motion: And therefore all the Angles described round the point C would be proportional to the Times, and the *Earth* seen from C would not appear to move slower in A than in P; but viewed from the Center of the Ecliptick, because at A it is farther distant than in P, it would appear to describe less Arches in equal times: And therefore when the *Earth* is in A, and a Spectator in it, observing the Sun in ♋, will find that he moves slower than when the *Earth* is in P, and the Sun is seen in ♑. And because the Arch of the Circle M A N is greater than a Semicircle, and N P M less than one; it is evident that there is more Time required to describe the Arch N A M than N P M: But in the time the *Earth* is carried thro' the Periphery N A M, the Sun seems to describe the Northern Semicircle of the Ecliptick, *viz.* ♈, ♋, ♎: And while the *Earth* is moving thro' the Arch M P N, the Sun will seem to have gone thro' the other, or the Southern Semicircle ♎, ♑, ♈. From hence the reason is plain why the Sun stays longer in the Northern Signs than he does in the Southern.

The Determinations of the Eccentricity and Position of the Apsides *on this Supposition.*

UPON these Suppositions they thus determined the Eccentricity and Position of the *Apsis*. In the same Year observe the Moments of Time wherein the Sun enters both the Equinoctial Points, *viz.* the Vernal and Autumnal, as also the place of the Sun in the Ecliptick in any other intermediate Time; which suppose to be in ♌, the *Earth* being really in ♒. When the *Earth* is in the point of its Orbit N, the Sun is seen in the point ♈; then the *Earth* coming to L, the Sun appears in ♌; and when it has arrived in M the Sun will be observed in ♎. Draw to the place of the *Earth* in L the right Lines S L, C L. Let likewise C M, M N and C N be joined; and let C M and S L cut one another in O. By Observations of the Places of the Sun we have the Angle ♈ S ♌, as likewise its Complement to two Right-Angles ♒ S ♈. Also by the distance of the Time between the Observations we have the

the Arch L M or the Angle L C M, as alſo the Arch N A M, theſe being proportional to the Times: Therefore we have likewiſe the Arch M P N and the Angle M C N. In the Iſoſceles Triangle M C N, having the Angle M C N, we have likewiſe the two Angles at the Baſe M and N: But in the Triangle M O S we have the Angle M S O and the Angle M: Therefore we have alſo the Angle M O S and L O C which is vertical and equal to it. Suppoſe L C the Radius of the Eccentrick to conſiſt of 100000 equal parts, then in the Triangle L O C, having all the Angles and the ſide L C we can find the ſide O C. But we know M C which is equal to L C: Therefore we have M O. In the Triangle M O S we have all the Angles and one ſide M O, and therefore we ſhall have O S. Laſtly, In the Triangle S O C having S O and O C, and the Angle S O C which is the Complement of the Angle S O M to two Right-Angles, we ſhall find S C the Eccentricity, and the Angle O S C; to which add the Angle M S O, and we ſhall have the Angle M S A or the Arch ♈ ♑; which ſhews the Poſition of the *Aphelion* or its diſtance from the Equinoctial point ♈.

BY this Method the Ancients found the Eccentricity to be 3450 of ſuch parts as the Radius of the Eccentrick was 100000; from which they eaſily calculated the Motion and place of the Sun for any given Time, in the manner following. In the Orbit of the *Earth* let A P be the Line of the *Apſides*, and ſuppoſe the *Earth* at L deſcribing its circular Orbit, the Arch A L or the Angle A C L proportional to the time will be the *Earth's* mean *Anomaly*, as the Arch of the Ecliptick ♑ ♒, or the Angle ♑ S ♒ is the true Anomaly. Having now the mean Anomaly we have its Sine L Q, and its Co-ſine C Q, to which add the known Eccentricity, and we ſhall have S Q: Say as S Q is to L Q, ſo is the Radius to the Tangent of an Angle, which is Q S L; which therefore will be known. Or thus, In the Triangle S C L we have

Lecture XXII. the sides S C and C L, and the Angle S C L the Complement of the mean Anomaly to two Right-Angles: Therefore we can find the Angle L S C or L S A the true Anomaly; for as C L + C S : C L — C S :: Tangent of half the Angle L C A to a fourth, which will be the Tangent of half the difference of the Angles C S L and C L S: And because S C and C L are given and constant Quantities, the Difference of the Logarithms of C L + C S and C L — C S will be a constant Quantity; and if it be always substracted from the Log. Tangent of half the Angle LCA, we shall have the Log. Tangent of half the Difference of the Angles C L S and C S L: But we have their Sum, and consequently the Angle L S A will be known; which shews the place of the *Earth* in the Ecliptick seen from the Sun, and the point opposite is the place of the Sun seen from the *Earth*. In the first half Circle of Anomaly A L P, the mean Anomaly A C L is greater than the true Anomaly A S L. For the external Angle A C L is greater than the internal and opposite A S L: And if from the mean Anomaly A C L you take away the Angle C L S, there will remain the Angle L S C the true Anomaly. In the second Semicircle of Anomaly, the mean Anomaly is less than the true. For suppose the *Earth* in R, the mean Anomaly is the Arch A P R, or casting away the Semicircle the Arch P R, or the Angle P C R: But the true Anomaly rejecting the Semicircle is P S R, which is equal to P C R and C R S. Therefore, if to the Mean Anomaly we add the Angle C R S we shall have the true Anomaly P S R, and the place of the *Earth* in the Ecliptick. The Angle C L S or C R S is called the *Equation* or *Prosthaphæresis*, because sometimes it is to be added, sometimes to be substracted from the mean Motion, that we may have the true Motion or place of the *Earth*.

THIS Theory of the Antients answered well enough to the apparent Motions of the Sun, which was founded on Observations that were not

very accurately made. But it was evident from Observations of the other Planets, that their Motions could not be accounted for by such a Theory. And even in the Sun itself there is a *Phænomenon* which is not to be explained by the Theory of the Antients; but clearly overturns that Theory, and proves it to be false, *viz.* By the most accurate Observations we find that the apparent Diameter of the Sun, when he is in his *Apogæon*, is 31′. 29″; in his *Perigæon* it is 32′. 33″. But the apparent Diameters are reciprocally as the Sun's distances. From whence we find that the true distance in the *Apogæon* is to the distance in the *Perigæon* as 1953 is to 1889, or as 101661 is to 98339; so that the Eccentricity is but 1661 of such parts, whereof the Radius of the Eccentrick is 100000: The Theory of the Antients makes the Eccentricity above double of this. And therefore that Theory must be false which supposes so great an Eccentricity: For if we should allow but one half for the Eccentricity, that would better answer to the apparent Diameters of the Sun, when they are nicely observed: But then on the other hand, so small an Eccentricity would not account for the Inequalities of the Sun's Motion, making the Center of the Eccentrick the Center of the middle Motion: For by computing, we find the *Equations* or *Prosthaphæreses* twice as great as what they would amount to with half only of the Eccentricity of the Antients. And therefore it is plain that this Theory of the Antients must be false.

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The Theory of the Antients is not true.

THE sagacious *Kepler* observing this, shewed that the Eccentricity was indeed to be bisected; but so, that the Center of the Eccentrick was in D, in the middle point between the Sun and the point C; from which C, if the Motion of the *Earth* were viewed, it would appear equal. This point C, which was distant from the Center of the Eccentrick by half the Eccentricity of the Antients, was called the Center of the middle Motion, because from it the Motion of the *Earth* would

Kepler's Correction of it.

Lecture XXII. would always be seen in a mean Motion, between its quick and flow progress in the Ecliptick.

'TIS true, *Copernicus* and many other *Astronomers* thought it absurd to suppose the *Earth* carried in a Circle whose Center was not the Center of the equal Motion; for then the *Earth*'s Motion must not only be in Appearance, but really in it self unequal; and in some parts of the Periphery of its Orbit it would move faster, in other slower, contrary to their establish'd Maxim of having all the Motions perfectly uniform.

Kepler's *Elliptick Theory.*

BUT *Kepler*, when he had demonstrated that *Mars* and the other Planets were not carried round the Sun in circular, but in Elliptical Orbits; and that the Sun was in one of the *Foci* of those Ellipses; and that the Planets in moving round him did so regulate their Motions, that a Line or Ray drawn from the Sun to the Planet did sweep an *Elliptick Area* or space always proportional to the Time the Planet moved. He thought it but reasonable to suppose the *Earth* in turning round the Sun should observe the same Law, and be carried likewise in an Elliptick Orbit. This Theory answers exactly to all Appearances; but it follows from it that there are no Centers of equal or middle Motion from which the Planets can be seen to describe Angles proportional to the Times. And therefore many *Astronomers* still adhering to the Opinion that there were Centers of equal Motion, rejected this Theory of *Kepler*'s; but for all that they retained the Elliptick Form of the Planetary Orbits. And because in the Axis of an Ellipse there are two points equally distant from the Center, which are called the *Foci*, in one of which they, with *Kepler*, placed the Sun; the other, which was distant from the Sun the double of the Eccentricity, they imagined to be the Center of equal Motion, and round it they suppos'd the Planets to describe Angles proportional to the Times; which indeed in Ellipses, that are not very Eccentrical, is nearly true, as *Kepler* himself acknowledges,

There are no Centers of middle Motion.

and

and we shall hereafter demonstrate. This Hypothesis they liked the better, because there was no direct or Geometrical Method in the Theory of *Kepler*, to find out the true Anomaly from the Mean, which by the other Theory they could easily find. Upon the account of this deficiency of Method, many *Astronomers* objected to *Kepler* ἀγεωμετρησίαν, or want of *Geometry* in his Theory; and rejecting it, went upon other Hypothesis which did not so well agree with the true Laws of Nature; and they feigned, that in each Orbit there was a certain point for the Center of equal Motion, round which the Planets described Angles proportional to the Times: But since the Theory of *Kepler* is that which does really obtain, and only has place in Nature; and all Observations declare that the Planets do really regulate their Motions by its Laws; it is not to be rejected upon the account of a want in *Geometry*, nor is the fault to be layed upon the Theory, which is rather to be imputed to the unskilfulness of the *Astronomers* in *Geometry*. We therefore, that we may remove this blemish of want of *Geometry* for the future, in the following *Lecture* will shew a direct Method of finding the true Anomaly of a Planet from its mean Anomaly given.

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Kepler's *Theory esteemed ungeometrical.*

LECTURE XXIII.

Of the Motion of a Planet in an Ellipse, And the Solution of Kepler's *Problem about the cutting of the* Elliptick Area.

THE Great *Kepler* was the first who demonstrated that the Planets did not move in circular Orbits, but that they were carried round the Sun in Elliptical ones, all which had one common *Focus*, in which the Sun resided: And that the Planets in their Motions constantly observed a certain Law, *viz.* that a Ray or Line reaching from the Sun to the Planet did sweep Elliptical Spaces that were proportional to the Times.

By Kepler's *Theory Sir* Isaac Newton *found out the Physical Causes of the Planets Motions.*

THIS admirable and Divine Invention of the sagacious *Kepler* was owing to the exact Observations of *Tycho Brahe*; and is so much more to be valued, for that by the help of it, the most incomparable *Philosopher* Sir *Isaac Newton* discovered the Universal Laws of Motion, the System of the Universe, and the whole Body of the Celestial *Philosophy*, which was intirely unknown before. *Kepler* also demonstrated, from Observations of the Motions, that in all the Planets their periodical Times were in a sesquiplicate proportion of their mean distances from the Sun, or of the greater Axes of the Ellipses, which are equal to twice the mean distances; that is, the Squares of the periodical Times are constantly as the Cubes of the greater Axes: And therefore if in two differen-

The proportion of the Planets periodical Times to their Distances found out by Kepler.

ferent Ellipses the greater Axes be called A, a, their periodical Times T and t; then we shall have the Analogy $T^2 : t^2 :: A^3 : a^3$, and $T : t :: A^{\frac{3}{2}} : a^{\frac{3}{2}}$.

HENCE it follows that in different Ellipses, the Area's described by two Planets in the same Time, are in subduplicate Proportion of the Parameters or *Latera recta* of the Ellipses, which I thus prove. It is known from the Property of the Ellipse that its Area is as the Rectangle under the two Axes of it; that is, if the two Axes of the greater Ellipse be called A and M, and the two Axes of the smaller Ellipse be called a and m; the Area of the greater Ellipse will be to the Area of the lesser as $A \times M$ is to $a \times m$. And therefore when we are speaking of the Proportion of the Area's, we may put these Rectangles instead of the Area's. In the greater Ellipse call the Area described in a given Time X, the Area described in the lesser Ellipse in the same time x, and the Time given in which they are described y; the *Latera recta* of the Ellipses call L and l, the periodical Times T and t. From the Theory above explained it follows that $X : A \times M :: y : T$, also that $a \times m : x :: t : y$. And therefore by Equality of proportion, 'twill be $X \times a \times m : x \times A \times M :: t : T :: a^{\frac{3}{2}} : A^{\frac{3}{2}}$. But since the lesser Axis is a mean proportional between the greater Axis and the *Latus rectum*, M will be $= A^{\frac{1}{2}} \times L^{\frac{1}{2}}$, and $m = a^{\frac{1}{2}} l^{\frac{1}{2}}$: And therefore $X \times a^{\frac{3}{2}} l^{\frac{1}{2}} : x \times A^{\frac{3}{2}} L^{\frac{1}{2}} :: a^{\frac{3}{2}} : A^{\frac{3}{2}}$. And therefore $X \times l^{\frac{1}{2}} : x \times L^{\frac{1}{2}} :: 1 : 1$; that is in proportion of Equality: And therefore $X : x :: L^{\frac{1}{2}} : l^{\frac{1}{2}}$. And therefore in different Ellipses, the Area's described in the same time are as the square Roots of their *Latera recta*.

The Area's described in the same Time proportional to the Latera recta *of the Ellipses.*

SINCE therefore the Law by which the Planets regulate their Motions is the equal or uniform Description of the Area's, it is impossible that

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that the Planets can every where move with the ſame uniform Velocity, but it muſt conſtantly be changed: So that going from the *Perihelion* to the *Aphelion* they muſt conſtantly ſlacken their Pace; but as they deſcend from the *Aphelion* to the *Perihelion* they muſt again quicken their Motions; And in the *Aphelion* they have the ſloweſt, in the *Perihelion* the quickeſt Motion: And the Velocity will be every where reciprocally as a Perpendicular that falls upon a Right Line paſſing thro' the Planet and touching the Orbit. Let D A F be an Ellipſe, whoſe *Focus* is S; and ſuppoſe the Arches A B, *a b* thereof to be gone over by the Planet in equal times that are exceeding ſmall, the Triangles S A B and S *a b* will be equal, for they are the Area's that the carrying Ray deſcribes in equal times. From the *Focus* S let fall on the Tangents the Perpendiculars S P, S *p*, and the Triangle SAB will be equal to $\frac{1}{2}$ SP × AB: So likewiſe the Triangle S *a b* will be equal to $\frac{1}{2}$ S *p* × *a b*: And therefore S P : S *p* :: *a b* : A B: But A B and *a b*, ſince they are Lines deſcribed in the ſame Time, are as the Velocities: Wherefore the Velocity in A is to the Velocity in *a* as S *p* is to S P the Perpendicular. Mr. *De Moivre*, in the *Philoſophical Tranſactions* N°. 352, has likewiſe demonſtrated the two following *Theorems* concerning the Elliptick Motion.

The Velocity every where reciprocal to the Squares of their diſtances.

Plate XXII. Fig. 3.

THEOREM I.

A Theorem to determine the proportion of the Velocity.

Table XVI. Fig. 7.

LET A P B be the Elliptick Orbit, in which ſuppoſe a Planet to move round the Sun in the Focus *S. Let C be the Center of the Ellipſe, C B half the greater Axis, C D half the leſſer, and F the other* Focus. *The Planet being in P, draw the Right Lines S P, F P; then the Velocity of the Planet in P, will be to the Velocity in its mean diſtance S D, in a ſubduplicate proportion of its diſtance F P from the* Focus *F, to its diſtance S P from the* Focus *S.*

Let the Right Line E P G touch the Ellipſe in P, and from each of the *Foci* on the Tangent let fall

fall the Perpendiculars SE, FG; and let SH be a Perpendicular on the Tangent DH. The Velocity in P is, as we have ſhewed, to the Velocity in D, as SH is to SE: And therefore the Square of the Velocity in P is to the Square of the Velocity in D, as SH Square or CD Square to SE Square; that is, by the Nature of the Ellipſe (becauſe CD Square is equal to $SE \times FG$) as $SE \times FG$ is to SE Square, or as FG to SE. But becauſe of the equiangular Triangles FG is to SE as FP is to SP: Wherefore the Square of the Velocity in P is to the Square of the Velocity in D as FD is to SP: And conſequently the Velocity in P is to the Velocity in D as $\sqrt{FP}$ is to $\sqrt{SP}$, which was to be demonſtrated.

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THEOREM II.

THE Radius is to the Sine of the Angle SPE as $\sqrt{SP \times FP}$ to CD. For SP Square is to $SP \times FP :: SP : FP :: SE : FG :: SE$ ſquare : $SE \times FG :: SE$ ſquare : CD ſquare. And by Alternation of Proportion SP ſquare : SE ſquare :: $SP \times FP$: CD ſquare: And therefore $SP : SE :: \sqrt{SP \times FP} : CD$: But $SP : SE ::$ Radius is to the Sine of the Angle SPE. Therefore as the Radius is to the Sine of the Angle SPE, ſo is $\sqrt{SP \times FP}$ to CD, which was to be demonſtrated.

WE have already ſhewed the Proportion by which the abſolute Velocity increaſes or decreaſes: But we have another *Theorem* for determining the angular Velocity, or the Angle which a Planet ſeen from the Sun will appear to deſcribe in a ſmall Particle of Time: For it is every where reciprocally in a duplicate proportion of the diſtance from the Sun; which I thus demonſtrate. At the Center S, at the diſtances SB, S*b* deſcribe the ſmall Arches BE, *be*, where AB, *ab* are the ſmall Elliptick Arches deſcribed in equal Times:

The angular Velocity at the Sun is as the Square of their diſtances reciprocally.

Plate XXII. Fig. 3.

In

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In S B take S m equal to S b, and draw the ſmall Arch mn: And the angular Velocity in b is to the angular Velocity in B as the Arch be is to the Arch mn: But the proportion of be to mn is compounded of the proportion of be to B E, and of B E to mn. And becauſe the Triangles B S A and b S a are equal, be will be to B E as S B is to S b: And becauſe the Arches B E and mn are ſimilar, B E is to mn likewiſe as S B to S m or as S B to S b: Wherefore the proportion of be to mn is compounded of the proportion of S B to S b, and again of S B to S b; that is, the angular Velocity at b is to the angular Velocity at B as the ſquare of S B is to the ſquare of S b, that is reciprocally as the ſquares of the Diſtances.

The angular Velocity of a Planet compared with an equal Velocity of a body moving in a Circle.

Plate XXII. Fig. 4.

BUT for to explain more clearly the Inequality of the Planets Motions, and the various Increaſe and Decreaſe of their angular Velocities, it will be requiſite to compare their Motions in different points of their Orbit, with an equal and uniform Motion of a body moving in a Circle: Let therefore the Ellipſe A E B F be the Orbit of a Planet in whoſe *Focus* is the Sun S. its greater Axis A B and leſſer O Q. At the Center S and diſtance S E, which is a mean proportional between A K and O K the two ſemiaxes, deſcribe the Circle C E G F. The Area of this Circle will be equal to the Area of the Ellipſe, as it is eaſily to be demonſtrated from the Nature of the Ellipſe: And let us ſuppoſe a point to move with an uniform or equal Motion thro' the Periphery C E G F, in the ſame time that the Planet deſcribes the Ellipſe: And when the Planet is in its *Aphelion* A, let the circulating point be in C, in the Line of the *Apſides*. The Motion of this point will repreſent the equal or middle Motion of the Planet, and the point will deſcribe round S Area's or Sectors of Circles which are proportional to the Times, and equal to the Elliptick Area's the Planet at the ſame time deſcribes. Let now the equal Motion or the Angle round S proportional

portional to the Time be C S M; and take the Area A S P equal to the Sector C S M, and then the place of the Planet in its own Orbit will be P, and the Angle M S D, the difference between the true Motion of the Planet and its mean Motion, is the Equation or *Prosthaphæresis*: And the Area A C D P will be equal to the Sector D S M, and consequently proportional to the *Prosthaphæresis*; And consequently where this Area is biggest, there the *Prosthaphæresis* or the Equation will be biggest: But the Area is biggest in the point E, where the Circle and the Ellipse cut each other. For when the Planet descends further to R, the Equation becomes proportional to the difference of the Area's A C E and *m* E R, or to the Area G B R *m*. For when the Planet is in R, let V be the place of the point moving uniformly in the Circle, the Sector C S V will be equal to the Elliptick Area A S R: And taking away the common spaces, the Area A C E less the Area R E *m* is equal to the Sector V S *m* or to the Equation.

Lecture XXIII.

The Area proportional to the Prosthaphæresis.

Where the Equation is greatest.

IN the *Perihelion* the equal Motion and the true Motion of the Planet coincide; for the Semicircle C E G is equal to the Semiellipse A E B. But after the Planet departs from the *Perihelion* B, its Motion is constantly quicker, and it goes before the point moving equally with the mean Motion. For let the Angle G S Z be proportional to the Time, take the Area B S Y equal to the Sector G S Z, and Y will be the place of the Planet in its Orbit; and the Angle B S Y will be greater than the Angle G S Z; and the Area G B Y L will be equal to the Sector Z S L, whose Angle is the Equation: And where the Area G B Y L is greatest, there the Equation is greatest, that is, in the point F, where the Circle and Ellipse cut one another. In A the Velocity of the Planet is the least of all, because the distance S A is the greatest; from thence the Planet descending to its *Perihelion*, its Velocity will constantly encrease; but it will still be less than the mean Velocity, till it comes to E, the Intersection of the Ellipse

Lecture XXII. Ellipse and Circle: And there its Velocity becomes just equal to the mean; which I thus prove. When the Planet is in E, let the point going with the equal or mean Velocity be in *m*, and the Area's described round S in the same infinitely small Time be *n* S E and the Sector *i* S *m*, which will be equal. And therefore *h* E × E S is equal to *i m* × *m s*: And therefore because S *m* and S E are equal, *h* E and *i m* must be equal; and the Angle *n* S E will be equal to the Angle *i* S *m*. At the point therefore E the angular Velocity of the Planet is equal to its mean Velocity: The Planet going from E, and approaching still nearer to its *Perihelion*, the Velocity grows bigger than the mean Velocity, and its distance from the Sun being constantly decreasing, the Velocity will continually increase, till it comes to the *Perihelion*, where it is the greatest of all, because the distance S B is the least of all. The Planet departing from thence, and ascending to the *Aphelion*, it leaves the point which proceeds constantly with the middle Motion, behind it; but as it goes farther off from the Sun its Velocity decreases, but is still bigger than the mean Velocity, till it comes to F, the point of Intersection of the Ellipse and the Circle, where the Planet's angular Velocity is again equal to the mean angular Velocity; and when it has passed that point its Velocity becomes less than the mean, and constantly diminishes till it arrives at the *Aphelion*, where it is the least of all; its distance from the Sun being then greatest of all.

SINCE therefore each Planet in different parts of its Orbit has different Degrees of Velocities, and the only Equality which is observed in its Circulation round the Sun is the equal Description or Increase of the Elliptick Area, which grows bigger uniformly with the Time; for to determine the place of a Planet in its Orbit at any given Time, we must take an Elliptick Area that is proportional to the Time. And to do this it is necessary to solve the following *Problem*.

KEPLER's PROBLEM.

To find the Position of a Right Line, which passing thro' one of the Foci *of an Ellipse, shall cut off an Area described by its Motion, which shall be to the whole Area of the Ellipse in a given Proportion.*

LET the Ellipse be A P B, whose *Focus* is S. I must find the Position of the Right Line S P, which cuts off the Trilineal Area A S P, to which the whole Area of the Ellipse has the same Proportion that the Periodical Time of the Planet has to any other given Time; which Position being found we shall have the place the Planet is in at the given point of Time. Or let A Q B be a Semi-circle described on the greatest Axis of the Ellipse; we must draw from S the Line S Q, which shall cut off the Area A S Q, to which the Area of the whole Circle is in the above-mentioned Proportion. For by such a Section of a Circle the Section of the Ellipse is easily found out, by letting fall from the point Q a Perpendicular on the Axis A B; which will cut the Ellipse in the point P required, to which draw the Line S P, and it will be the Right Line which divides the Area of the Ellipse in the given Proportion; so that P will be the place of the Planet. For the Elliptick Segment A P H is to the circular Segment A Q H as H P is to H Q; that is, as the Area of the whole Ellipse is to the Area of the whole Circle, as is known from the nature of the Ellipse: But the Triangle S P H is to the Triangle S Q H in the very same proportion by *Prop.* 1. *El.* VI. And therefore by *Prop.* 12. *El.* V. the Elliptick Area A S P is to the circular Area A S Q, as the Area Table XXII. Fig. 5.

of

Lecture XXIII.

of the whole Ellipſe is to the whole Circle: And by Alternation the Area A S P is to the whole Ellipſis as the Area A S Q is to the Circle. Hence if we have a Method of drawing thro' S a Line which will cut the Area of the Circle in a given proportion, it will be eaſy to cut the Area of the Ellipſe in the ſame proportion.

KEPLER, who firſt propoſed the *Problem*, knew no direct Method of computing the Planet's place from the Time; and expreſly tells us, that there was no direct way of finding, from the Time given, the true Anomaly of the Planet, or its place in its Orbit. And therefore he found it neceſſary to go thro' every Degree of the Semicircle A Q B; and to ſearch from the Arch A Q, which he called the *Anomaly of the Eccentrick*, the Time which was expreſſed by the Area A S Q, which is proportional to the mean Anomaly; as alſo the Angle A S P, which gives the true Place and true Anomaly of the Planet, which he computed by Calculation. And therefore becauſe he could not directly and Geometrically ſolve the *Problem*, ſome *Aſtronomers* objected to him an *ἀγεωμετρησία* or want of *Geometry*; and that he was ſo fond of Phyſical Cauſes, that he had departed from *Geometry*; and they blamed his *Aſtronomy* as not being Geometrical, ſince it was founded on ſuch a Theory. And therefore that they might eſcape the committing of ſuch a fault, they went upon other *Hypotheſes*, and feigned a point round which the Planets Motion ſhould be equal, or the Angles proportional to the Times: And from thence, the mean Anomaly being given, they calculated the true place of the Planet. But the Calculations founded on theſe *Hypotheſes* was found not to anſwer Obſervations: For there is really no fixed Point which is the Center of equal Motion, round which the Planets deſcribe Angles proportional to the Times: And the only Theory that anſwers all Obſervations is that above explained of *Kepler*. And therefore the *Aſtronomers* muſt now for ever embrace this Theory of *Kepler*, ſince it

The Anomaly of the Eccentrick.

not only agrees perfectly with the Motions of the Heavens; but also lays most elegantly open the Cause and Source of all those Motions. *Kepler* himself valued this Theory so much, that he chose rather to take up with an indirect Method of Calculation, than contrive another *Hypothesis* that was not agreeable to the Nature of Things; and for this the ablest Judges were not displeased with him. Therefore to take away this blemish of want of *Geometry* out of our *Astronomy*, we will here shew a direct Method by which the Area of an Ellipse, or of a Circle which is equivalent, may be cut in a given Proportion.

LET AQB be a Semicircle whose Diameter is the greater Axis of the Ellipse, its Center C, and S the *Focus* of the Ellipse in which the Sun is placed. Thro' the place of the Planet imagine a Perpendicular QH to be drawn to the Axis, meeting with the Circle in Q: Then the Area ASQ will be to the whole Circle as the given Time is to the Periodical Time of the Planet. Draw CQ, and from S let fall upon it, produced if required, the Perpendicular SF: The Area ASQ is equal to the Sector ACQ and the Triangle QSC; that is, equal $\frac{1}{2}$QC × AQ + $\frac{1}{2}$QC × SF. And therefore because $\frac{1}{2}$QC is a constant Quantity, the Area ASQ will be always proportional to the Arch AQ + the Right Line SF, when the Motion is from the *Aphelion* to the *Perihelion*: But when the Planet ascends from the *Perihelion* to the *Aphelion*, the Area BSq is equal to the Sector BCq — Triangle CSq: And therefore it will be proportional to the Arch Bq — the Right Line Sf. Hence if we take the Arch AN or Bn proportional to the Time, AQ + SF will be equal to AN, or Bq — Sf = Bn; for then AN and Bn will be proportional to the Area's ASQ and BSq.

Table XXII. Fig. 6.

HENCE if we have the Arch AQ, and add to it the Arch QN, which is equal to the Right Line SF; the Arch AN will be proportional to the Time, or equal to the mean Anomaly

Lecture XXIII. of the Planet: And therefore if we have the true Anomaly of a Planet, we may easily find the mean, or the Time. For let QC be to SC as 57,29578 (which Number expresses the length of an Arch in Degrees and parts of a Degree that is equal to the Radius) to a fourth Number: And we shall have an Arch equal to SC in Degrees and decimal Parts. Call this Arch B: And because SC is to SF, as the Radius is to the Sine of the Angle SCF or ACQ, say as the Radius is to the Sine of ACQ, so is the Arch B to a fourth; and then we shall have, in Degrees and decimal Parts, an Arch in the Periphery AQB, which is equal to the Right Line SF: And because SF is equal to QN, we have the Arch QN, and also the Arch AN, which is proportional to the Time.

LET us explain this by Examples in the Orbit of *Mars*. The Eccentricity of this Orbit is to its mean distance as 14100 is to 152369. And therefore the Logarithm of the Arch B, which is equal to SC is 0,7244446: And therefore if we would have the mean Anomaly when the Anomaly of the Eccentrick is one Degree, add the Log. Sine of 1 Degree to the Log. of B, the Sum is 8,9662999: This being the Log. of the Number 0,092533, expresses the length of the Arch QN in decimal parts of a Degree. And therefore the Arch AN or the mean Anomaly is 1,092533 or $1^{\circ}.\ 5'.\ 33''$. In like manner, if the Anomaly of the Eccentrick be 30°, to its Log. Sine add the constant Log. of B; and the Sum will be 0,4234146; which is the Log. of the Number 2,651. And therefore the mean Anomaly AN answering to 30 Degrees of the Eccentrick Anomaly, is 32,651, or $32^{\circ}.39'.3''$. This Method is much quicker and easier than that which *Kepler* gives, where, by an indirect Method and the Rule of false Position, he shews how to compute the true Anomaly from the mean.

LET us now come to the Method I promised of directly finding the true Anomaly from the mean

mean. In the Figure let the Arch A N be the Anomaly, or proportional to the Time; A Q the Anomaly of the Eccentrick which is to be found, Call the Arch N Q y, and the Sine of A N call e, and Co-sine f; and let the Eccentricity S C be g. The Sine of the Arch A Q is equal to the Sine of the Arch A N — N Q, equal to the Sine of the Arch A N — y. But we have demonstrated in the Elements of *Trigonometry*, that if the Sine of the Arch A N be e, the Sine of the Arch A N — y, or of A Q, will be $e - \frac{fy}{1} - \frac{ey^2}{1.2} + \frac{fy^3}{1.2.3} + \frac{ey^4}{1.2.3.4}$ &c. But the Radius which is 1 is to the Sine of the Arch A Q as S C or g is to S F or N Q; that is to y: And therefore $y = ge - \frac{gfy}{1} - \frac{gey^2}{1.2} + \frac{gfy^3}{1.2.3} + \frac{gey^4}{1.2.3.4}$ &c. And therefore we have $ge = y + \frac{gfy}{1} + \frac{gey^2}{1.2} - \frac{gfy^3}{1.2.3} - \frac{gey^4}{1.2.3.4}$ &c. Let $ge = z$, and $1 + fg$ call a, $\frac{ge}{2} = b$, $\frac{gf}{1.2.3} = c$; and $\frac{ge}{1.2.3.4} = d$. And the Equation will be in this Form $z = ay + by^2 - cy^3 + dy^4$ &c. And therefore by the Method of Reversion of Series invented by Sir ISAAC NEWTON, we have $y = \frac{z}{a} - \frac{bz^2}{a^3} + \frac{2b^2 + ac}{a^5} z^3 - \frac{5abc - 5b^3 + a^2d}{a^7} \times z^4$ &c. But because $b = \frac{ge}{2} = \frac{z}{2}$ and $d = \frac{z}{24}$, we shall have $y = \frac{z}{a} - \frac{z^3}{2a^3} + \frac{cz^3}{a^4} - \frac{5cz^5}{2a^6}$ &c. But if the Arch AN be greater than 90 Degrees and less than 270, then ge or

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 $z =$

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$z = y - gfy + \frac{gey^2}{2} + \frac{gfy^3}{1.2.3} - \frac{gey^4}{1.2.3.4}$. And then $a = 1 - gf$, and $y = \frac{z}{a} - \frac{z^3}{2a^3} - \frac{ez^3}{a^4}$ &c. This Series expresses the Arch QN in parts whereof the Radius is 100000: But to have it in Degrees and parts of a Degree: Say as the Radius is to this Series, so is 57,29578, which are the Degrees of an Arch equal to the Radius, to a fourth; consequently, since the Radius is Unity, if we multiply the Series by 57,29578, which number call R, we shall have the Arch y in Degrees and decimal parts $= \frac{Rz}{a} - \frac{Rz^3}{2a^3} + \frac{Rcz^5}{a^4}$ &c. The very first Term of this Series $\frac{Rz}{a}$ is sufficient to determine the Anomaly of the Eccentrick in almost all the Planets, nearly enough. For in *Mars* the Error seldom exceeds the 200*th* part of a Degree: In the *Earth* it is less than the 10000*th* part of a Degree. But it will be best to shew the use of this Method by Examples.

IN the Earth's Orbit the Eccentricity is 0,01691, when the mean distance CQ is 1. Suppose we are to find the Anomaly of the Eccentrick, and the equated Anomaly when the mean Anomaly is 30 Degrees,

The Log. of Eccentricity is	—	8,2281436
The Log. Sine of 30°	— —	9,6989700
The Log. of R	— —	1,7581226
The Log. of Rz	— —	9,6852362
The Log. of a substract	—	0,0063137
The Log. of the Arch y	— —	9,6789225

To which answers the Number 0,47744, or in sexagesimal Numbers 28′. 38″: The rest of the Terms don't amount to the 10000*th* part of a Degree, and may therefore be neglected. If therefore from 30 Degrees we deduct 28′. 38″, we shall have the Arch AQ 28°. 31′, 22″. In the Triangle

gle QCS we have the fides QC, CS and the Angle SCQ: Wherefore we fhall have the Angle QSC. The Analogy is QC + CS or AS : QC − CS or BS :: Tangent $\frac{CSQ + CQS}{2}$: Tangent of $\frac{CSQ - CQS}{2}$. Therefore if from the Tangent of half the Angle ACQ we fubftract a conftant Log. 0,0146893, we fhall have the Tangent of an Angle, which added to half the Angle ACQ gives the Angle CSQ or ASQ, which in the prefent Cafe is 29°. 3′. 7″. But for to find the Angle ASP we muft diminifh the Tangent of the Angle ASQ, in the Proportion of the bigger Axis of the Ellipfe to its leffer. Therefore from the Logarithmick Tangent of ASQ take away the conftant Log. 0,0000622, which is the Log. of the *Ratio* of the greater Axis to the lefs, and we fhall have the Log. Tangent of the Angle ASP, which Angle is equal to 29°. 2′. 54″. And this is the coequated Anomaly.

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Plate XXII. Fig. 5.

IN the Orbit of *Mars* the Eccentricity is 14100 of fuch parts as the mean diftance is 152369. And therefore the Log. of the *Ratio* of SC to CQ is 8,9663226 = Log. of *g*. Let us find the Anomaly of the Eccentrick when the mean Anomaly is 1 Degree,

The Log. of Eccentricity —	8,9663226
The Log. Sine of 1 Deg. —	8,2418453
The Log. of R — —	1,7581220
The Log. of R z — —	8,9662899
The Log. of *a* fubftract —	0,0384299
The Log. of $\frac{Rz}{a}$ — —	8,9278600

Firft, THE Number anfwering this Log. is 0,08497, and gives the bignefs of the Arch NQ; and the Error is lefs than the 30000*th* part of a Degree.

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2*dly*, SUPPOSE the mean Anomaly is 45 Degrees, and I am to find the Anomaly of the Eccentrick.

The Log. of Eccentricity	—	8,9663226
The Log. Sine of 45°	—	9,8494850
The Log. of R	— —	1,7581220
The Log. of R z	——	0,5739296
The Log. of a subtract	—	0,0275249
The Log. of $\frac{Rz}{a}$	——	0,5464047

To which answers the Number 3,5189, which is more than the Truth by about 150th part of a Degree: And to correct this Error take the second Term of the Series — $\frac{\overline{Ra + 2Rc} \times z^3}{2a^4}$, which will be found equal to the Fraction 0,0065, and substract this from the first, there will remain 3,5124, which expresses the Arch NQ true to 100000*th* parts of a Degree.

3*dly*, LET us find out the Anomaly of the Eccentrick when the mean Motion is 100 Degrees: In this Case $a = 1 - gf = 0,983930$.

The Log. Eccentricity or of g		8,9663226
The Log. Sine of 100° or of 80°		9,9933515
The Log. of R	— —	1,7581220
The Log. of R z	——	0,7177961
The Log. of a subtract	—	9,9929598
The Log. of $\frac{Rz}{a}$	——	0,7248363

The Number answering to this Log. is 5,3068, which is greater than the Truth by about the 50*th* part of a Degree: And therefore to correct this Error, double the Log. of $\frac{z}{a}$, and to the Product add the Log. of $\frac{Rz}{a}$, and we shall have the Log. of

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of $\frac{Rz^3}{a^3}$, and the Number anſwering to it is 0,04552, whoſe half 0,02276 is equal to $\frac{Rz^3}{2a^3}$. This being ſubſtracted from the former, there will remain 5,2841 for the Arch NQ; which is not the 10000*th* part of a Degree diſtant from the Truth. It's here to be obſerv'd, that though the ſecond Term of the Series be $-\frac{\overline{Ra+2Rc}\times z^3}{2a^4}$ yet the part of it $-\frac{Rz^3}{2a^3}$ is ſufficient to determine AQ truely to the 10000*th* part of a Degree.

HAVING found the Arch AQ or the Angle ACQ, we compute the Angle ASQ by the Reſolution of the Triangle QCS, whoſe ſides QC and CS are given, with the Angle contained between them: And then the Logarithm Tangent of the Angle ASQ is to be diminiſhed, by taking from it the Logarithm of the *Ratio* of the greater Axis to the leſs: And then there will remain the Logarithmick Tangent of the Angle ASP, which is the true or coequated Anomaly.

LECTURE XXIV.

Sir ISAAC NEWTON's *Solution of* Kepler's *Problem, and* Ward's *Elliptick Hypothesis explained.*

OUR Method of Solution explained in the preceding *Lecture*, and that of Sir ISAAC NEWTON's delivered by him in his Principles, *pag.* 101, are built upon the same Foundation; which is, that the Right Line SF is equal in length to the Arch QN: But the *Newtonian* Method is not unlike to that used by the *Analysts*, when they extract the Roots of affected Equations: And it is so much more to be valued, that it not only gives easily the Planets Places whose Orbits are nearly circular; but almost with the same Ease it may be used to determine the Comets places, who have very Eccentrick Orbits. And this may likewise be performed by our Method, if instead of the Arch AN we take another Arch A more nearly equal to AQ, whose Sine is e; and instead of making $z = ge$, suppose $z = ge + A - AN$. And finding the Sine of the Arch $A \pm y$ we shall come to an Equation of the same Form with the former, where z and y are much less, and consequently the Series will converge much faster.

I will here explain the *Newtonian* Method, since it is of great Use and Expedition, for the sake of those who are willing to calculate Tables upon Principles grounded on the true Laws of Motion, and not upon absurd Hypotheses.

WE

Plate XXII

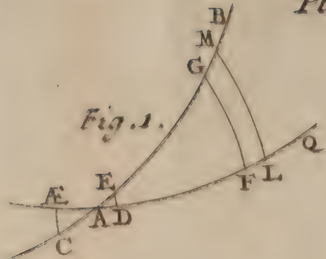

Fig. 1.
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Fig. 2.
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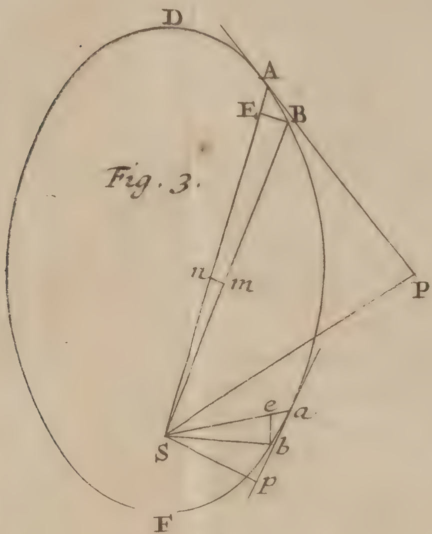

Fig. 3.
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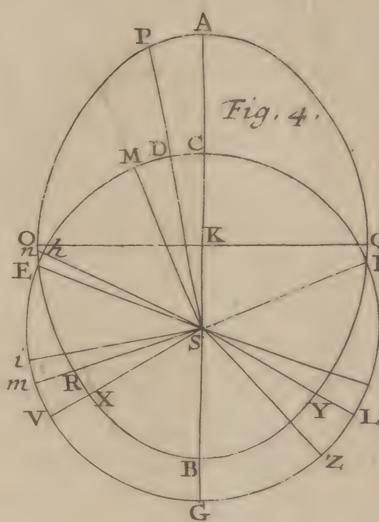

Fig. 4.
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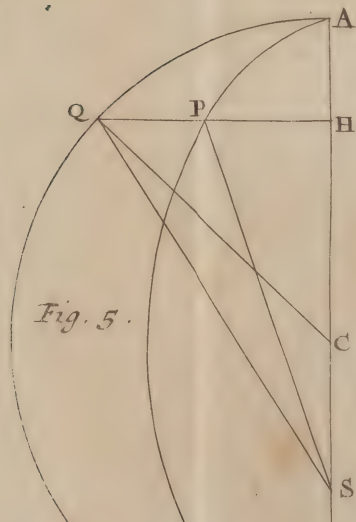

Fig. 5.
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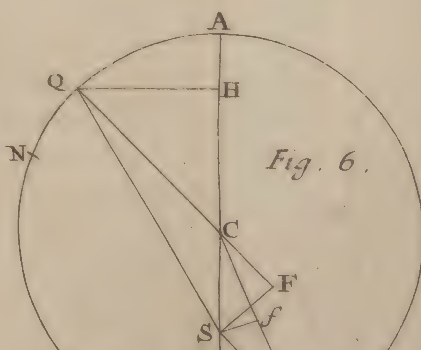

Fig. 6.
A
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WE have already shewed that if the Arch AQ be the Anomaly of the Eccentrick, that together with the Right Line SF let fall from S upon the Radius CQ perpendicularly, will be proportional to the Time, when the Planet descends from the *Aphelion* to the *Perihelion*; and the Difference between the Arch BQ and SF proportional to the time when it ascends from the *Perihelion* to the *Aphelion*: And therefore if we take the Arch AN or BN proportional to the Time, the Arch QN will be equal to SF. Therefore to find in Degrees and decimal parts the measure of an Arch in the Periphery which is equal to SF: Say as CQ is to CS, so is 57,29578 Degrees, which is equal to the Radius, to a fourth: This Number will express the bigness of an Arch in the Periphery AQB which is equal to CS: The Log. of this Arch call B. And because SC is to SF as the Radius is to the Sine of the Angle ACQ; say as the Radius is to this Sine, so is the Arch whose Log. is B to another which call D; then this Arch D will be equal to SF. And therefore if at the given Time the Arch AN and the Area ASQ are proportional each to the Time, and I take NP equal to D, the point P will fall on Q: But if the Area ASQ be not exactly proportional to the Time, the point P will either fall above or below Q, according as the Area ASQ is bigger or less than the Truth. Let the true Area be ASq, and upon Cq let fall the Perpendicular SE; which by what we have already shewed is equal to Nq: And therefore SE − SF or SF − SE, that is nearly the Line LE is equal to qP = QP − Qq or Qq − QP. Now if the Angle QCq be small, we have CE : Cq :: LE : Qq :: QP − Qq : Qq. And therefore CE + Cq : Cq :: QP : Qq. After the same way, when Bq is less than a Quadrant, Cq − CE : Cq :: QP : Qq. When the Planet is near the *Aphelion* or *Perihelion*, CE becomes nearly equal to CS; and CQ + CE is almost the same with

Lecture XXIV.

Table XXIII. Fig. 1.

AS:

Lecture XXIV. A S: And therefore $QP : Qq :: AS : AC$, when the Arch Aq is leſs than a Quadrant; but when Bq is leſs than a Quadrant, then as $SB : CB :: QP : Qq$. Say as $CS : CQ :: R$ the Radius to a Line L, and then $CQ = \frac{CS \times L}{R}$. Alſo the Radius is to the Coſine of ACQ as $SC : CF$ or CE, which are nearly equal: Wherefore $CE = \frac{SC \times \textit{Cosine}\ AQ}{R}$, whence we have the Analogy $QP : Qq :: \frac{SC \times L + SC \times \textit{Cof.}\ AQ}{R} : \frac{CS \times L}{R} :: L + \text{Cofine}\ AQ : L$; when AQ is leſs than a Quadrant: But if it be greater than a Quadrant, QP will be to $Qq :: L - \text{Cofine}\ AQ : L$. And in this manner, if there be an Arch taken as Aq, which is either a little leſs or bigger than the Truth, we ſhall find the Arch AQ, which is to be added or ſubſtracted; ſo that the Area ASQ may be nearly proportional to the Time. And if inſtead of AQ we take another Arch AQ, and argue as in the former Arch, we ſhall have a new Aq nearer to the Truth: And by this means we ſhall conſtantly approach to the true Arch, ſo that the Difference may be leſs than any given Quantity.

THERE is no need of explaining this Method any farther, we will only illuſtrate it with Examples in the Motions of the Planet *Mars*. In *Mars*'s Orbit the Logarithm B is 0,7244446; and the Longitude L is 1080631 of ſuch parts as the Radius is 100000.

LET us find the Angle ACQ, when the mean Anomaly or Arch proportional to the Time is only one Degree: Becauſe CS is almoſt the 10*th* part of CA. I ſuppoſe AQ to be 0,9 Deg. that is a tenth part leſs than the mean Anomaly. Add the Log. Sine of 0,9 to the Log. B, and the Sum is 8,9205466 = to the Log. of the Number 0,083281; this Number expreſſes the bigneſs of an

an Arch equal to $SF = NP$: And if the Arch AQ had been rightly aſſum'd, $AN - NP$ had been equal to AQ, and $QP = 0$. But in the preſent Caſe QP is equal 0,01671; from which if I take away its tenth part, becauſe AS is greater than AC by about a tenth part, we ſhall have $Qq = 0{,}01504$, which being added to AQ gives $Aq = 0{,}91504$.

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2*dly*, LET the Arch AN or the mean Anomaly be 2 Degrees; I ſuppoſe the Arch AQ to be 1,83, almoſt double of the former; and adding to its Log. Sine the Log. B, the Sum is 9,2286992, the Log. of the Number 0,16931. And then $QP = 0{,}00069$; from which ſubſtracting a tenth part, Qq is nearly $= 0{,}000063$, and Aq 1,83063, which is not the 1000*th* part of a Degree different from the Truth.

3*dly*, SUPPOSE the Arch proportional to the Time to be 3 Degrees, I take AQ to be $2{,}745 = 1{,}83 + 0{,}915$; and to its Log. Sine adding the Log. B, we have the Log. of the Number $0{,}25392 = NP$, and $AN - NP = 2{,}74638$, therefore $Qq = 0{,}001$ nearly, and $Aq = 2{,}746$: So that by one Addition of two Logarithms we have the Arch Aq true to the thouſandth part of a Degree.

4*thly*, NOW if we ſhould not proceed by ſingle Degrees, but were to find the Angle ACQ when the mean Anomaly is much larger; for Example 45°: I make my Suppoſition that the Arch AQ is 40 Degrees, and to its Log. Sine add the Log. B; the Sum is 0,5320121, equal to the Log. of the Number 3,4081, which Number ſubſtracted from 45, leaves $AN - NP = 41{,}5919$, which exceeds the Arch AQ by 1,5919. And therefore if we take as $L +$ Coſine AQ to L, ſo 1,5919 to a fourth, we ſhall have the Arch Qq 1,4865. And therefore $Aq = 41{,}4865$, which does not differ much above the thouſandth part of a Degree from the Truth. But without this proportion we might have found Aq by taking an Arch which is ſomewhat leſs than $AN - NP$, but nearly equal to it. Suppoſe we had made $AQ = 41{,}5$, and ad-

ding

Lecture XXIV. ding its Log. Sine to the Log. B, we shall have another Arch N P = 3,5132, which subtracted from A N gives 41,4868 for a new A q. And this Arch is easier found than by the former proportion; and besides comes nearer to the Truth than the last A q was.

5*thly*, AFTER having found A q or the Anomaly of the Eccentrick, that answers to the mean Anomaly of 45 Degrees; if we should again proceed by single Degrees, by only one Addition of two Logarithms, we may find the Anomaly of the Eccentrick to all the following Degrees of the Semicircle, *viz.* when the mean Anomaly is 46 Degrees I make A Q to be 42,4, and adding its Log. Sine to the Log. B, I find A N — N P 42,4249; to which if I make the new A Q equal, I shall have an A q, which is not 1000*th* part of a Degree distant from the true Anomaly of the Eccentrick. So likewise when the mean Anomaly is 47 Degrees, I take A Q 43,36 = to the former A q + the Increment that accrues to it by adding a Degree: And adding the Log. B to the Log. Sine of 43,36, the Sum is the Log. of the Number 3,6402, which substracted from A N leaves A N — N P = 43,3598 equal to a new A q: And this Arch is about the 10000*th* part of a Degree different from the true Anomaly of the Eccentrick.

6*thly*, IF again passing over the intermediate Degrees I would find the Arch A q when the mean Anomaly is 100 Degrees; I make A Q equal 96 Degrees, and adding its Log. Sine to the constant Log. B, the Sum is the Log. of the Number 5,273, and A N — N P = 94,727. Therefore I put again A Q = 94,72, and adding together its Log. Sine and the Log. B, I have the Log. of the Number 5,285, which substracted from A N leaves A q = to 94,715. In like manner when the mean Anomaly is 101 Degrees, I make A Q 95,71; and I find N P to be 5,2756, which substracted from 101, leaves A q 95,7244. And here again, if we proceed by Degrees, we shall have

have the Eccentrick Anomaly constantly by the Addition of two Logarithms, one of which being constantly the same, may be set once down in a piece of Paper by itself, and the Labour sav'd of frequently transcribing it. Lecture XXIV.

LET us now pass to another sort of Orbit whose Eccentricity bears a great proportion to its mean distance. For Example, Let us suppose the *Aphelion* distance to be to the *Perihelion* distance as 70 is to 1; and such is nearly the Orbit of that Comet which Dr. *Halley* first found to compleat its Period in $75\frac{1}{2}$ Years. Here A C or C Q the mean distance is 35,5, and C S is 34,5 of such parts as S B is 1. And the constant Log. B is 1,7457133. We must find the Arch B q when the mean Anomaly computed from the *Perihelion* is $\frac{1}{100}$ of a Degree. I suppose B Q to be 0,35: To its Log. Sine add the Log. of B, and the Sum is the Log. of the Number 0,34013, which added to the Arch A N makes ,35013. If this Arch had been only 35, B Q had been rightly taken; but the difference is 0,00013. And therefore because C B is to S B as 35,5 to 1; multiply the difference ,00013 by 35,5, and we shall have Q q = ,004615, and the Arch B q = 0,354615; and the Error less than ,0003 of a Degree. Again, let the mean Motion be ,02, I put B Q = 0,71, and adding its Log. Sine and B together, I have the Log. of the Number 0,68998, and B N + N P = ,70998: The difference is 0,00002; which multiply by 35,5, and the Product substracted from B Q leaves B q = 0,7092; and the Error is not greater than the $\frac{1}{10000}$ part of a Degree. If the mean Anomaly be 0,03, I make B Q = 1,06, and adding its Log. Sine to B, I have the Log. of the Number 1,03008, to which add the Arch B N; the Sum is 1,060088, which is greater than B Q: Wherefore if the difference ,00008 be multiplied by 35,5, and the Product added to B Q, we shall have B q = 1,06284. In the same manner when the mean Anomaly is ,04, I suppose B Q 1,4, and I find P N = 1,3604, to which adding

Table XXII. Fig. 6.

Lecture XXIV. adding ,04 the Sum is 1,4004, which exceeds 1,4 by ,0004; multiply this difference by 35,5, and the Product will be ,0142 = Q*q*, and therefore B*q* = 1,4142. In all these Examples the Errors are very small, seldom exceeding the 1000*th* part of a Degree.

LET us now find the Anomaly of the Eccentrick, when the mean Anomaly is one Degree. Here I make BQ = 20 Degrees, and adding its Log. Sine to B, I have the Log. of the Number 19,045, to which adding 1 the Sum is 20,045, and is greater than 20 by ,045. And because in this Example L — Cosine BQ is to L as 1 is to 11,5 nearly: I multiply the difference ,045 by 11,5, and the Product 0,5175 added to BQ makes 20,5175. Therefore 2*dly* I make BQ 20,51, and NP will be 19,5092; to which adding BN the Sum is 20,5092. And therefore if the difference ,0008 be multiplied by 11,5, and the Product ,0092 substracted from BQ, there will remain B*q* = 20,5008.

Lastly, LET the mean Anomaly be 2 Degrees; I put BQ = 30 Degrees, and then I find NP 27,84; to which adding 2, and the Sum is 29,84, which is less than 30 Degrees: Multiply the difference ,16 by 6,3, (for L — Cosine BQ is to L as 6,3 to 1) and we have 1,008 = Q*q*: And therefore this Arch substracted from BQ gives B*q* = 28,982. Therefore to correct the Error, I put again BQ = 29 Degrees; and by a like process I find B*q* = 28,9672. Having found the Angle ACQ, the Angle ASQ is easily found. For in the Triangle QCS we have the sides QC, CS and the Angle QCS: Therefore we shall find the Angle ASQ and the side SQ; then say as the greater Axis of the Ellipse is to its less, so the Tangent of the Angle ASQ is to the Tangent of ASP, which will thereby be found; and it is the coequated or true Anomaly. Again, say as the secant of the Angle ASQ is to the secant of ASP, so is SQ to SP the distance of the Planet from the Sun. Or perhaps

Table XXII. Fig. 5, 6.

these

these things may be easier computed in this manner. Having the Arch A Q, we have its Sine Q H and its Cosine H C: But we have S C in such parts as the Radius or C Q is 100000; therefore we have H S. Say as the greater Axis of the Ellipse is to its less, so is Q H to P H, which will therefore be given. In the Rectangle Triangle P H S, we have also the sides P H and H S, wherefore we can find P S H the true Anomaly, and P S the distance of the Planet from the Sun. Lecture XXIV.

BECAUSE in the *Aphelions* and *Perihelions* the points Q and N, or the mean and true place of a Planet coincide; and in the first Semicircle of Anomaly the mean place is before the true place, in the second the mean place is behind the true; if we have determined the Position of the *Apsides* of the *Earth*'s Orbit, we shall know the Time when the true and mean place coincide. For when the Sun is observed in that point of the Eclíptick where the *Perihelion* is, then the Earth is in the *Aphelion*. And having this Moment of Time by *Astronomical* Tables, we shall have the mean Anomaly for any other Time, as likewise the Arch A N. For these Arches are computed according to the proportion of the Times, and are placed orderly in the Tables. Now having for any point of Time the Arch A N, we have shewed, how from thence we may compute the true Anomaly, and the place of the Earth in the Ecliptick, to which the place of the Sun is always opposite.

BESIDES the Theory of *Kepler*, according to which the Planets do really regulate their Motions, there is another Elliptick Hypothesis which has been chiefly improved by two most Celebrated Astronomers, *Ismael Bullialdus* and Dr. *Seth Ward*, formerly Professor in this Chair and afterwards Bishop of *Salisbury*, by whose Pains *Astronomy* has been much advanced. And since this Hypothesis does not want Elegance, and a neatness in Geometry; and besides it admits of an easiness in computing, we will here briefly explain

Lecture XXIV. explain it. In this Hypothesis, with *Kepler*, it is supposed that the Planets Orbits are *Ellipses*, and that they have all one common Focus in which the Sun resides. Moreover they suppose that each Planet does move in the Periphery of its Orbit, in such a manner, that drawing Rays or Lines to the other Focus, they describe Angles proportional to the Times. These things being supposed Dr. *Ward* shews an elegant Method of finding the true Anomaly from the Mean, having determined the Species of the Planet's Orbit; And it is as followeth.

Table XXIII Fig. 2. LET APB be the Ellipse which the Planet describes, AP the Line of the Apsides, S the Focus in which the Sun is placed, F the other or the upper Focus, which is the Center of equal Motion. Let the Angle AFL be proportional to the time, or be the Mean Anomaly, then L will be the place of the Planet in its Orbit, and the Angle ASL the Co-equated, or true Anomaly. Produce FL to E, so that FE may be equal to AP the greater Axis of the Ellipse; and therefore since by the Nature of the Ellipse FL and LS are equal to the same AP, then LE must be equal to LS, and the Triangle LSE will be an Isosceles Triangle; and therefore the Angles E and ESL are equal, and the exterior Angle FLS being the Sum of both, will be the double of each, or double of the Angle LES. Therefore in the Triangle EFS, having FE and FS, and the Angle EFS, which is the Complement of LFA to two rights, we can find the Angle E, whose double is equal to the Angle FLS, which therefore will be known: But the Angle AFL is equal to the two Angles FSL and FLS, and therefore the Angle FLS is the *Prosthaphæresis* or the Equation, which is to be substracted from the Mean Anomaly, or added to it, to have the true Anomaly.

IN resolving the Triangle EFS, having EF and FS, the Analogy is $\frac{1}{2}$ES + $\frac{1}{2}$FS : $\frac{1}{2}$ES — $\frac{1}{2}$FS, that is, as AS to SP :: Tang. $\frac{1}{2}$ AFE : Tangent of $\frac{1}{2}$ difference of the Angles E and FSE; but be-

because the Angle E is = LSE, FSL is the difference of the Angles E and FSE; wherefore the Angle found by the Analogy being doubled, gives the Angles FSL, which is the true Anomaly. Now the Practise here is ectreamly easy; for because AS and SP are constant Quantities, the difference of their Logarithms is a constant Quantity, wherefore a given Number is to be added to Log. Tangent of half the Mean Anomaly, and then we shall have the Tangent of half the true Anomaly. Moreover, in the Triangle LFS, having all the Angles and the Side SF, we can find SL the distance of the Planet from the Sun. Lecture XXIV.

THIS Hypothesis of Dr. *Ward*'s is a very useful Approximation, and serves to shorten the Calculation, and make it easy: But yet it is still only an Approximation, and does not come up to the Truth: We will here shew the reason of it. Let APB be the Orbit of the Planet, AQB the Circle circumscribed, the Arch AQ the Anomaly of the Eccentrick, and AN the Mean Anomaly. From the Center C draw NC, and QG parallel to it; the Angle QGA is equal to NCA or the Mean Anomaly, and CG will be nearly equal to CS, but a little less than it. For from the Focus S on QC, let fall the Perpendicular SF, which we shewed before to be equal to the Arch QN: But because the Arch QN is small, its Sine will be almost equal to the Arch; and therefore GO a perpendicular on NC, will be nearly equal to SF, but somewhat less. But the Triangles GOC and SFC are nearly equiangular, (for NCQ the difference of the Angles GCO and SCF is very small,) and therefore because OG is almost equal to SF, but a little less than it; CG will be almost equal to CS, but somewhat less. The other *Focus* of the Ellipse then must be a little above the Point G, but very near it; and if we draw from the Planet's place the Line PL parallel to QG, the Point L will be likewise above the Point G, but yet not far distant from it; and therefore the Point L and the other Focus of the Plate XXIII. Fig. 3.

Lecture XXIV. Ellipse do nearly coincide. But the Angle PLA is equal to NCA the Mean *Anomalia*; and the Point L nearly coinciding with the other *Focus*, the Line drawn from P to the other *Focus* will make an Angle with the Axis, nearly equal to the Angle PLA or NCA, that is to the Mean Anomaly. And therefore the Angles at the superior *Focus* are nearly proportional to the times.

WHERE the Angles NCA and QCA or SCF differ but little from one another, that is, where the Angle NCQ is but small and the Eccentricity, the Points G and L, are nearly coincident with the superior *Focus*. And therefore this Theory is accurate enough to answer to the Motion of the Earth, whose Orbit is nearly Circular: But in the other Planets, and particularly *Mars* and *Mercury*, it does not do so well. And therefore *Bullialdus* from four places of *Mars* observed by *Tycho* in the first and third Quadrant of Anomaly, found that *Mars* was further advanced in his Orbit than he ought to be by this Theory. But in the second and fourth Quadrants, *Mars's* true Anomaly was found to be less than it should be according to this Hypothesis: And therefore *Bullialdus* gave it the following Correction. Upon the Diameter AP, which is the greater Axis of the Ellipsis, describe the Circle ADP. Let AFL be the Mean Anomaly; through L draw the Line QLG perpendicular to the Axis, meeting with the Circle in Q. Joyn FQ which cuts the Ellipse in ♈, and ♈ will be the place of the Planet in its Orbit, answering to the Mean Anomaly AFL. Now the Angle AFQ, answering to the Mean Anomaly AFL, is easily found by taking an Angle whose Tangent is to the Tangent of AFL, as the greater Axis of the Ellipse is to the lesser. And having the Angle AFQ or AF♈, the Angle AS♈ is found in the same manner as before the Angle ASL was found.

Plate XXIII Fig. 2.

THE Calculations we have here explained: Suppose that the Species or Forms of the Orbits are given, as likewise their Positions. We shall afterwards shew a way by which the Orbits of

the

the other Planets are determined: But the Form and Position of the Earth's Orbit is to be found by the following Methods. First observe the Apparent Diameter of the Sun, as likewise his Motion; for when the Earth is in its *Aphelion*, the Sun's Diameter is the least of all, and his Motion slowest, the Earth being there at the greatest distance from the Sun. In the *Perihelion*, it coming nearest the Sun, we shall observe his Diameter to appear biggest: Let any right Line SP represent the *Perihelion* distance of the Sun: Say, as the Apparent Diameter of the Sun in the *Aphelion* is to its Apparent Diameter in the *Perihelion*, so is SP to a Fourth. In SP produced take SD equal to this fourth, and it will be the *Aphelion* distance; bisect PD in C, and CS will be the Eccentricity and C the Center. Describe an Ellipse whose *Focus* is S, and greatest Axis PD, that Ellipse will be of the same Form with the Earth's Orbit, and the Points of the Ecliptick where the Sun's Diameter appears the biggest and the least, shew the Position of the *Apsides*, or the *Aphelion* and *Perihelion*: But because the Diameter of the Sun, in the *Aphelion* and *Perihelion*, is scarcely seen to alter its bigness for some Days; it will be very difficult to determine the Position of the *Apsides* by Observations made on the Apparent Diameter of the Sun only: And therefore it will be better to find out the *Aphelion* and *Perihelion* distances and Positions by observing the Sun's Motion: For the Angular Velocity of the Earth, and the Apparent Motion of the Sun, which is equal to it, is always reciprocally as the Square of the Distance, as we have above demonstrated.

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Plate XXIII Fig. 4.

THEREFORE to determine the Species of the Ellipse in which the Earth moves, we must observe the Apparent Velocities of the Sun when it is greatest and least. Call the least A, and the greatest B, and let any Right Line SP, represent the *Perihelion* distance: Say, as A is to B, so is SP to another Line C: Produce SP to D, so that SD may be a mean Proportional between SP and

Lecture XXIV. and C; this Line SD will represent the *Aphelion* distance: And therefore if the Ellipsis be described whose *Focus* is S and its greater Axis P D, that Ellipse will be of the same Form with the Earth's Orbit. For because S P, S D and C are continually Proportional, P S Square will be to D S Square, as S P is to C, or as as A to B, that is as the Velocities. Moreover, if the Places of the Ecliptick be diligently marked where the Velocities are greatest and least, in those Points will the *Apsides* be situated. Lastly, if there be two Places of the Ecliptick observed, where the Sun's Apparent Velocities are equal, and the Arch of the Ecliptick between the two places be Bisected, the Point of bisection and its opposite, will shew the Places of the *Apsides*. But these Methods require Observations that are very nice and accurate, such as can scarcely be made.

FROM the Theory of Dr. *Ward* we have a more certain Method of finding the Form of the Orbit, by three Observations of the Sun, and marking the Time between them, which does likewise determine the Position of the *Apsides*. Let A B P D C be the Orbit of the Earth, S the *Focus* in which the Sun is placed, F the other *Focus*: The *Apsides* A and P. Let B, C and D be three Places of the Earth in the Ecliptick, which are found by observing three Places of the Sun to which they are opposite. At the Center F and distance F M, equal to the greatest Axis of the Ellipse, describe the Circle M H E L, and let the Lines F B, F C, F D produced, meet with the Circle in the Points G, H, E. Draw likewise from the *Focus* S, the Lines S B, S C, S D, as also S G, S H, and S E. We have the Angles B S C, B S D and C S D, for they are measured by the Arches of the Ecliptick intercepted between the Points observed. But according to this Theory, the Earth moves in the Perimeter of an Ellipse in such a manner, that it describes Angles about the *Focus* F, that are proportional to the Times: And therefore we shall have the Angles B F C, B F D, and C F D, taking

Plate XXIII Fig. 5.

each

each of them ſuch that they may have the ſame proportion to four Right Angles, as the times between the Obſervations has to the whole Periodical Time. Moreover, twice the Angle F G S, that is the Angle F B S, is the difference of the Angles A F B and A S B: This we ſhewed before. And the double of the Angle FHS is the difference of the Angles A F C and A S C; the difference of the Angles B F C and B S C, will therefore be equal to 2 F G S + 2 F H S. But becauſe we know the Angles B F C and B S C, we know likewiſe their difference; therefore we have the Sum of the Angles F G S and F H S. But the Angle F G S, is the difference of the Angles BFA and G S A; and the Angle F H S is the difference of the Angles H F A and H S A: Whence both the Angles F G S and F H S will be equal to the difference of the Angles B F C and G S H. But we have the Angle B F A, and the Sum of the Angles F G S and F H S; and therefore we have the Angle G S H. In the ſame manner we can find the Angle GSE. Alſo in the ſame manner the Angle F E S doubled, is the difference of the Angles D F A and D S A; alſo the double of the Angle F H S, is the difference of the Angles C F A and C S A. And therefore twice the Angle F E S — twice the Angle F H S will be equal to the difference of the Angles C F D and C S D; but we have the Angles C F D and C S D: And therefore we have half their difference, that is FES—FHS. But the Angle F E S — F S H is the difference of the Angles C F D and H S E, and we have the Angle C F D; wherefore we have the Angle H S E. We have therefore all the Angles at F, *viz.* B F C, B F D, C F D, and all the Angles at S, *viz.* B S C, B S D, C S D; as alſo G S H, G S E, H S E. Theſe things being laid down.

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EXPRESS the Line S H by any Number, *viz.* 100000, and produce E S, till it meets with the Periphery in L, joyn H L, L G and H G. In the Triangle H S L, we have the Angle H S L, the Complement of H S E to two Rights: And the

Lecture XXIV. the Angle H L S equal to half the Angle H F E, by the 20 *Prop. El.* III. and the side H S 100000; wherefore we shall find the side S L: Then in the Triangle S L G, we have the Angle L S G, the complement of the known Angle E S G to two Rights, and the Angle S L G, being half the Angle E F G, by the 20 *Prop, El.* III. and the side S L, therefore we shall find S G. And again, In the Triangle S H G, we have the sides S H and S G, and the Angle H S G; and consequently we shall find the side H G, and the Angle S H G. In the Isosceles Triangle H F G, we have the Angle H F G and the Base H G, wherefore we shall find the side H F, which is equal to the greater Axis of the Ellipse; as also the Angle G H F, which being substracted from the known Angle G H S, leaves the Angle F H S known. Lastly, In the Triangle F H S, having F H and H S and the Angle F H S, we shall find the side S F, from which substracting the Angle H S C = F H S, there will remain the Angle CSF, which shews the Position of the *Apsides*.

THIS Method does suppose indeed that the Angles at the superior *Focus* be always proportional to the Times, which is not true. But in the Orbit of the Earth, whose Eccentricity is small, the Angles that are really described at that *Focus*, differ so little from the Angles that are proportional to the Time, that no sensible Error can arise from thence, in determining the Species and Position of the Orbit.

THE most Celebrated *Astronomer* Dr. *Edmund Halley*, from whose Labours *Astronomy* has received great improvements, hath contrived a Method, which depends on no Theory of the Earth's Motion: From which, by Observations alone, the Form and Position of the Orbit, are to be determined.

Table XXIII Fig. 6. SUPPOSE the Sun at S, A B C D the Orbit of the Earth, P the Planet *Mars*, who for this purpose is to be preferr'd or chosen before the others. First observe the true time and place, when *Mars* is

is in Oppoſition to the Sun, for then the Sun, the Earth and *Mars* are in one Right Line; or if it happens (as it often does) that *Mars* has any Latitude, the Sun, the Earth and *Mars* his Place reduced to the Ecliptick, are in a Right Line. Let the Sun, the Earth and *Mars*, have their Places in the Points S, A and P, in the Right Line S P. Since *Mars* his Period conſiſts of 687 Days, after that time *Mars* will return to the Point P, and ſeen from the Sun he will appear in the ſame Place as before, in which he was ſeen alſo from the Earth: But the Earth does not return to A till after $730\frac{1}{2}$ Days; and therefore when *Mars* is P it will be in B. and will obſerve the Sun in the Line S B, and *Mars* in the Line B P. By obſerving the Places of the Sun and *Mars*, we have all the Angles of the Triangle PBS. And ſuppoſing P S to conſiſt of 100000 Parts, we can find the diſtance S B in thoſe Parts, as likewiſe its Poſition. After the ſame manner, when *Mars* has finiſhed another Period, the Earth will be in C, and we can find the length of the Line S C and its Poſition; and likewiſe by the ſame Method another Line S D and its Poſition may be obtained: And by this means we are come to this *Geometrical* Problem. Having three Lines meeting in the *Focus* of an Ellipſe, all given in Length and Poſition, to find the Length of the Tranſverſe Axis, its Poſition and the diſtance of the *Foci*: which Problem the *Geometers* ſhew how to conſtruct, and we in the following Lectures will likewiſe give its Solution.

Lecture XXIV.

LECTURE XXV.

Of the Equation of TIME.

Motion the Measure of Time.

ALTHO' *Time* be in its own nature a real Quantity, as being endowed with the chief Properties of Quantity, Equality, Inequality and Proportion; yet for to meaſure this Quantity, we muſt have the Aid and Aſſiſtance of Motion, as a Meaſure to eſtimate and compare the Quantities of *Times*; and therefore *Time*, when it is conſidered as meaſurable, marks out ſome Motion: For if all Things were at reſt, we could by no means know the Flux or Quantity of *Time*, and the Duration of all Things would go on without Perception.

Uniform Motion the proper Meaſure.

BUT becauſe *Time* conſtantly flows equally, and in the ſame manner, for to meaſure it we muſt make uſe of ſuch a Motion, as is in itſelf ſimple, uniform, and always going on at the ſame rate; ſo that the Body which has this Motion, at leaſt as to its Periods, may always keep the ſame force, and yet go thro' equal Spaces in equal *Times*.

The Motions of the Sun & Moon the fiteſt Meaſures.

FOR common uſe we muſt take that Motion which is moſt remarkable, evident to every Body, and plain to common Senſe; ſuch is the Motion of the Stars, and chiefly of the Sun and Moon, which not only, by the common conſent of all Mankind, are agreed upon for this effect, but by the Almighty and wiſe Creator of the Universe are eſtabliſhed for this purpoſe: For in the

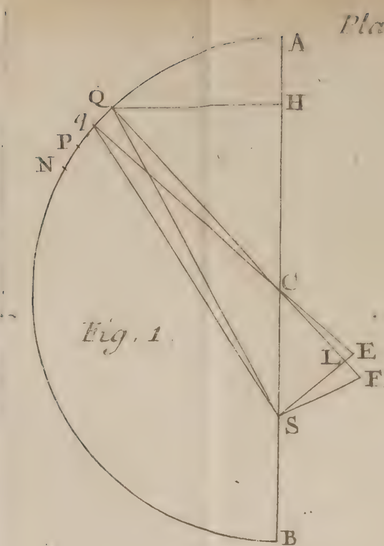

Fig. 1.

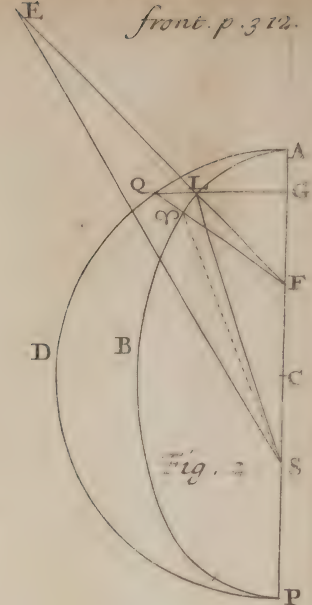

Fig. 2.

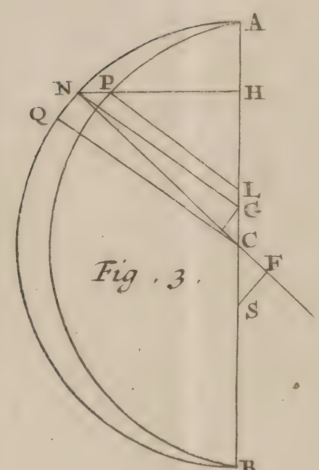

Fig. 3.

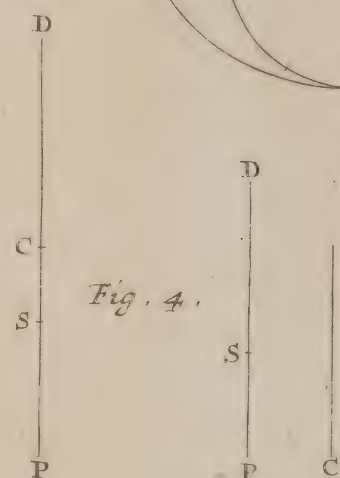

Fig. 4.

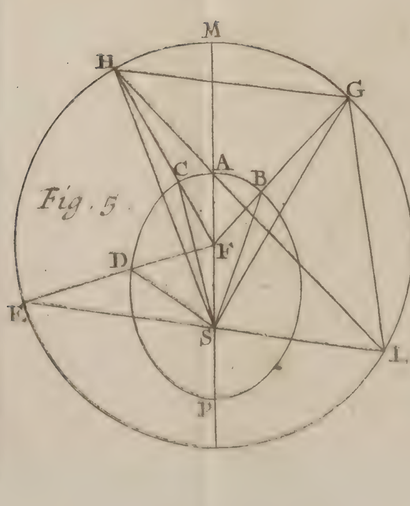

Fig. 5.

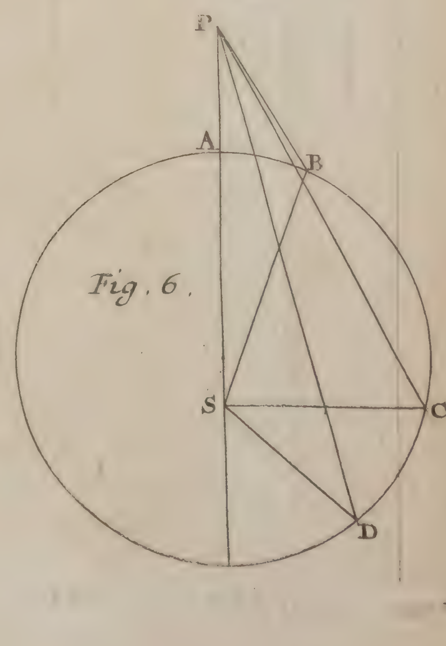

Fig. 6.

the Scriptures we read that God ſaid, *Let there be Lights in the Firmament of the Heaven, to divide the Day from the Night; and let them be for Signs and for Seaſons, and for Days and Years.* And therefore by the Celeſtial Motions, and chiefly by that of the Sun, are the *Times* rightly diſtinguiſhed and marked out. Who therefore dare ſay that the Sun will not tell us Truth! The *Aſtronomers* are the bold Men who tell us ſo; for they by their nice ſearch into Things, have found that the Sun's apparent Motion is no ways equal; they obſerve that he now and then ſlackens his Pace, and afterwards quickens it again: And therefore *Equal Time*, which goes on always at the ſame rate, cannot truly be meaſured by the Sun's Motion.

The diſtinction between the True and Equal Time.

HENCE the *Time* which the Sun's Motion ſhews, and which is called the *Apparent Time*, is different from that *Time* which flows uniformly and always at the ſame Rate, which is called by the *Aſtronomers* the *True and Equal Time*; according to which all the Celeſtial Motions are to be eſtimated regulated and ſettled. For upon the account of the unequal Motion of the Sun, and the Obliquity of the Ecliptick to the Equator, we have neither Days nor Hours perfectly equal, as we ſhall here ſhew.

THE Solar Day is that ſpace of *Time* which paſſes, while the Plane of the Meridian of any place paſſing thro' the Center of the Sun, by the Earth's Revolution turning round its own Axis, returns again to the Sun's Center; or it is the *Time* between one Mid-day and the next which comes after. Now if the Earth had no other Motion but that round its Axis, all the Days would be exactly equal to one another, and to the time of the Revolution round the ſaid Axis. But becauſe while the Earth is whirling round its Axis, it is alſo going forward in its proper Motion Eaſtward; when any Meridian has compleated its Revolution, after having paſs'd the Sun's Center, its Plane will not have then paſſed thro' the Sun,

Lecture XXV.

Table XXIV Fig. 1.

Sun, as is plain by the Figure. For let the Sun be S, A B a portion of the Ecliptick; let the Line M D represent any Meridian, whose Plane produced, passes thro' the Sun when the Earth is in A: Let the Earth proceed in its Orbit and come to B, while it has compleated a Revolution round its Axis; and then the Meridian M D will be in the Position *m d*, parallel to the former M D; and consequently will not as yet have passed thro' the Sun, nor will the Inhabitants under that Meridian have had their Mid-day. But the Meridian *d m* with its angular Motion must still go on before its Plane can pass thro' the Sun, and must describe the Angle *d* B *f*. And therefore all the Solar Days are longer than the *Time* of one Revolution round the Earth's Axis. If the Planes of all the Meridians were perpendicular to the Plane of the Earth's Orbit, and the Earth described this Orbit with an equal Motion, after any Meridian had compleated its Revolution, because M D and *m d* are parallel, the Angle *d* B *f* would be equal to the Angle B S A, and the Arches A *f* and A B similar: And because the *Times* are always equal, the Arch A B and the Angle *d* B *f* would constantly be of the same Quantity, and all the Solar Days would be equal to one another; and then the apparent and equal *Time* would agree. But neither of these two Cases have place in Nature; for the Earth does not proceed in its Orbit with an equal Motion; but in its *Aphelion* it describes a less Arch, in its *Perihelion* a greater. And moreover the Planes of the Meridians are not perpendicular to the Ecliptick, but to the Equator: And therefore the *Time* of the angular Motion *d* B *f*, which besides the intire Revolution is to be added to the space of a Solar Day to compleat it, is not always of the same quantity; whence the Solar Days will not be equal.

It is proved that the Solar Days are unequal.

The same is made plain by the apparent Motion of the Sun.

BUT perhaps this may appear plainer, if we pass from the real Motion of the Earth and consider the apparent Motion of the Sun; for it is by

by his apparent Motion that we measure the *Apparent Time*. And therefore you must observe that the Natural Solar Day is that space of *Time*, in which, by the Revolution of the whole Heavens, which is called the Revolution of the *Primum Mobile* or of the first moveable Orb, the whole Circumference of the Equator passes through the Meridian; and also so much more of the same Circle as answers to the apparent Motion of the Sun to the East, in the mean while.

The diurnal Arches of the Equator are not equal to the diurnal Arches of the Ecliptick.

BUT the Arch of the Equator passing thro' the Meridian, is not always equal to the correspondent Arch of the Ecliptick which passes thro' the same in the same time; but is sometimes bigger, and sometimes less than it, even tho' the Sun's Motion were equal in the Ecliptick: The difference between them arises from the oblique Position of the Ecliptick to the Equator, as is plain by the Figure. Suppose ♈ ♋ a Quadrant of the Ecliptick, and ♈ E a Quadrant of the Equator. Suppose the Arch ♈ A to be one Degree, which is nearly equal to the diurnal Motion of the Sun in the Ecliptick; for his mean Motion is 59′. 8″. Let A B be an Arch of the Circle of Declination passing thro' the Sun in A, and intercepted between the Equator and the Ecliptick. In the right-angular Triangle ♈ B A, having the side ♈ A 1 Degree, and the Angle A ♈ B, which is the Inclination of the Ecliptick to the Equator, and is nearly $23\frac{1}{2}$ Degrees, we shall find the side ♈ B 55′. 1″, almost 5′ less than the Arch ♈ A. Again, suppose the Arch of the Ecliptick ♈ C 89°. From thence we shall find the Arch of the Equator ♈ D 88°. 54′. 34″; but when the Arch of the Ecliptick ♈ ♋ is 90 Degrees, then A E, the correspondent Arch of the Equator, is also 90 Degrees. And the difference of the Arches ♈ C, ♈ D is 1°. 5′. 26″. And the difference of the Arches of the Equator ♈ B and D E is 10′. 25″, altho' the Arches of the Ecliptick ♈ A and C ♋ which answer to them are equal. From which it is evident, that the Arches

Table XXIV Fig. 2.

of

of the Equator anſwering to equal Arches of the Ecliptick are unequal: And therefore the diurnal Arches of the Equator which paſs through the Meridian are unequal; but they meaſure the Solar Days: Wherefore the Solar Days are unequal.

The ſecond Cauſe of the Inequality of Days.

BUT the Obliquity of the Ecliptick is not the only Cauſe of the Inequality of Days; for the very apparent Motion of the Sun in the Ecliptick is unequal; for he proceeds more ſlowly, and ſtays longer in the Northern Signs than in the Southern, by eight intire Days: And therefore if there were no Obliquity of the Ecliptick, by this cauſe alone the diurnal Arches of the Equator could not be equal. And therefore their Inequality will be much greater, upon account of theſe two Cauſes concurring together; that is, the unequal Motion of the Sun, and the Obliquity of the Ecliptick, which tho' they are ſometimes contrary to each other, and ſo diminiſh the Inequality; as it happens when the Arches of the Equator decreaſe on the account of the Obliquity of the Ecliptick, but by reaſon of the Sun's approaching the *Perigæon* they increaſe, and on the contrary: Yet ſometimes theſe two Cauſes concur to increaſe the Inequality, and neither of them depend one on the other, but each of them by itſelf has its Effect.

SINCE therefore the apparent Motion of the Sun to the Eaſt is unequal, it cannot be a fit meaſure of *Time*, which ſhould always go on at the ſame rate. And therefore the natural and apparent Days are no ways to be applied to meaſure the Celeſtial Motions, which do not depend upon the Motion of the Sun: Therefore the *Aſtronomers* found it neceſſary inſtead of theſe Solar Days to ſubſtitute in their place others that were equal, and a mean between the ſhorteſt and the longeſt; and by them to diſtinguiſh the Celeſtial Motions. And when theſe Motions have been computed according to the *Equal Time*, it is neceſſary to turn that *Time* again into the *Apparent Time*, that theſe Motions may be obſerved by us who mea-

measure and number our *Times* by the apparent Motion of the Sun. And on the contrary, if any Appearance in the Heavens, as for Example, an Eclipse were observed according to the *Apparent Time*, and according to it the *Astronomical* Tables were to be examined, to see if they did agree with it or not; it will be necessary to turn the *Apparent Time* into *Equal Time*, otherwise the observed *Phænomenon* will differ from that which is found by Computation. Lecture XXV.

BECAUSE we know no Body in Nature which preserves constantly a perfect uniform Motion; and yet such a Motion is only proper to measure equal Days and Hours: It is convenient to imagine some Body or Star which moves in the Equator Eastward, and which never quickens or slackens its pace, but goes thro' the Equator in precisely the same time as the Sun finishes his Period in the Ecliptick. The Motion of such a Star will rightly represent equal Time, and its diurnal Motion in the Equator will be daily 59′. 8″, the same as is the mean Motion of the Sun in the Ecliptick: And therefore the equal and middle Day is to be determined by the arrival of this Star to the Meridian, and is equal to the Time in which the whole Circumference of the Equator or 360 Degrees pass the Meridian; and besides that 59′. 8″: And because this Addition of 59′. 8″. always remains the same, all these mean Days will be constantly equal to each other.

SINCE the Sun goes unequally Eastward according to the Equator, sometimes it will come to the Meridian sooner than this imaginary Star, and sometimes he will touch it later than it does, and the difference is that which is between the *True* and *Apparent Time*. And this difference is known by having the place of the imaginary Star in the Equator, and the point of the Equator which comes to the Meridian with the Sun; for the Arch intercepted between them being converted into *Time*, shews the difference between *Equal* and *Apparent Time*, which is called the *Equation of* Time. *The* Equation of Time.

Lecture XXV.

of *Time.* And it is the *Time* that flows, while the Arch of the Equator intercepted between the point determining the Right-Aſcenſion of the Sun, and the place of the imaginary Star paſſes the Meridian.

LET ÆQ be a portion of the Equinoctial, EC of the Ecliptick, in which imagine S to be the place of the Sun, SA a Circle of Declination paſſing thro' the Sun, and meeting with the Equator in A, which will be the point which comes to the Meridian with the Sun. Suppoſe *m* to be the place of the imaginary Star which performs its Period in the Equator with an equal Motion: And when the Sun has arrived at the Meridian our imaginary Star will be diſtant from it, by the Arch *m* A; and if the point *m* be Eaſtward of the point A, it will come later to the Meridian than it, and the apparent *Time* will be faſter than the mean; but if the place of the Star *m* be more Weſterly than A, it will ſooner arrive at the Meridian, and the *Apparent Time* is ſlower than the mean. And the Arch of the Equator A *m* converted into *Time* is the Equation, which being added to or ſubſtracted from the *Apparent Time* gives the true, according as the point *m* is to the Eaſt or Weſt of the point A; and then we have the true *Time.* For to know the poſition of the point A in reſpect of *m*, and the Quantity of the Arch A *m*, take in the Equator the Arch ♈ *s* or ♎ *s* equal to the ♈ S or ♎ S in the Ecliptick; and then the Arch *s m* will be the diſtance between the true and mean place of the Sun, which therefore is given by the Sun's Anomaly; but the Arch A S is the difference between the *Hypothenuſa* ♈ S of the Right-angled Triangle ♈ S A, and its ſide or Baſe ♈ A, which may be found by *Trigonometry.* Moreover, the Arch A *m* is equal to either the Sum or Difference of the Arches A *s* and *s m*; and therefore when they are known, the Arch A *m* will be likewiſe known.

Table XXIV Fig. 3, 4.

The Equation of Time *conſiſts of two parts.*

MOREO-

MOREOVER we must observe, that in the first and third Quadrant of the Ecliptick, the point *s* falls upon the East side of the point A: And therefore the Arch A *s* being turned into *Time*, is to be substracted; because the point S comes later to the Meridian than the point A does. But in the second and fourth Quadrants the point *s* is more Westerly than A, and arrives at the Meridian before it: And therefore the Arch A *s* turned into *Time* is to be added, for to get the *Time* when the point S arrives at the Meridian. Suppose for Example A *s* be two Degrees, as it is when the Sun is in the 20*th* Degree of ♈; this Arch turned into *Time* is 8 Minutes: And therefore we must add 8′ to the *Apparent Time*, for to have the *Time* when the point S comes to the Meridian.

MOREOVER in the first Semicircle of Anomaly, that is while the Sun in this present Age goes from the seventh Degree of ♋ to the seventh of ♑, the mean Motion of the Sun is greater than its true Motion; therefore then the middle place precedes the true place. And therefore in all that Semicircle the point *m* will be to the East of the point *s*; and the Arch *m s* turned into *Time*, is to be substracted from the *Time* that the point S reaches the Meridian: But in the other Semicircle of Anomaly, after the Sun has left the *Perigæon*, or rather the Earth the *Perihelion*, the mean Motion is less than the true, and then the mean place follows the true; and consequently the point *m* is to the West of the point S, and comes sooner to the Meridian than it does: And therefore the Arch *m s* turned into *Time*, is to be added to the *Time* in which S touches the Meridian. Having now the distance of *Time* between the coming of the point *m* to the Meridian, and the coming of the point S to the same; as also the distance of *Time* between the arrivals of the points *s* and A to the Meridian, we shall have the distance of *Time* between the coming of the point *m* to the Meridian, and of the

Lecture XXV. the point A's arrival to the same; that is, we shall have the difference between the *Apparent and True Time*, which is the *Equation of Time.*

Two Tables for equating Time.

FOR the equating of *Time* the *Astronomers* compose two Tables, one for the Arch *s m*, which is to be entered into with the Anomaly of the Sun: And if the point *m* be Westward of the point *s*, they mark it with + or the Sign of Addition; but if it be on the other side, they place — or of Substraction. The other Table is for the Arch *s* A, which is the difference between the place of the Sun in the Eclipck and his Right-Ascension. And the Equations of this Table are likewise marked with the Signs of Addition or Substraction; as the point *s* is to the West or East of the point A. The Sum of these two Equations, if they be of the same kind, that is, both to be added or both to be substracted; or their difference, if their Affections be of different kinds, make up the absolute *Equation of Time.*

The Temporary Table.

THE Artists likewise make a Table composed of both the former; but it will only serve for a time: Yet it may be used for a whole Age without any sensible Error; for the same Degree of Anomaly keeps nearly in the same Degree of the Ecliptick the space of an Age: And therefore for the space of 50 Years these two Equations may be joined in one. But because of the Præcession of the Equinoxes, the Sun's *Apogæon* in process of Time changes its place in the Ecliptick, and goes Easterly with the Fixed Stars: And therefore in different Ages the same Degrees of Anomaly will fall upon different Degrees of the Ecliptick: And therefore one Table will not serve for all Ages.

When the Solar Days begin to be longer than the mean.

THE imaginary Star, by whose equal Motion we measure Time, goes constantly and uniformly forward to the East: But the point A which determines the Right-Ascension of the Sun, and marks out the apparent Time, has as it were a Libration, or goes backwards and forwards in

respect

respect of *m*: Sometimes it gets to the East of *m*, and sometimes is to the West of it, and sometimes coincides with it. And therefore when the point A has its relative Motion in respect of *m* Eastward, the point A is more East than the Star *m*, and then the Days are longer than the mean Days, which are measured by *Equal Time*; and the faster the point A goes to the East, so much the longer are the Solar Days: For besides the Revolution of the whole Heavens, the Arch to be added to make up the Solar Day is greater, because the point A goes a greater space Eastward. Hence it follows, that as soon as the relative Motion of the point A begins to be Eastward, the Solar Days begin likewise to be longer than the mean Days. I speak of the relative Motion in regard of the point *m*; for the absolute Motion of A is always Eastward: But when the point A is gone its farthest distance from *m* to the East, then it begins to come back again to *m*, and has its relative Motion Westward: But before that, the point A will be for a while stationary in respect of *m*, in the middle Time between its Recess and Access; and then the Solar Days will be equal to the mean Days; and in these Points the Equations will be greatest. When the Motion of the point A to the East is quickest, there the Days become the longest; and where it is the slowest, that is, where the Motion relative to *m* is Westward and greatest, there the Days are shortest. In the present Age wherein we live, when the Sun is in the 10*th* Degree of *Scorpio*, the point A is at its farthest distance from *m* to the West of it; and its distance then amounts to 4°. 2'. 45", and therefore the greatest *Equation* in Time is 16'. 11". From thence the Days begin to encrease, till the Sun comes to 22½ Degree of *Aquarius*, where it has gone to its farthest distance from *m* Eastward, it being there removed 3 Deg. 42½. Min. whence the greatest *Equation* of Time is 14'. 50": And from thence the relative Motion of the point A be-

Lecture XXV.

When the mean and Solar Days are equal.

At what times of the Year the Equations are greatest.

Lecture XXV. gins again to be Westward, till the Sun comes to the 24*th* Degree of *Taurus* or the *Bull*; and there the point A is removed from *m* 1 Deg. 1½ Min. to the West of the Star *m*, and the greatest *Equation* of Time is 4′. 6″. Thence it returns again to *m*, and moves Easterly, till the Sun comes into the 3½ Degrees of the *Lion*, where A is distant from *m* 1 Deg. 28½ Min. and the greatest *Equation* of Time is 5′. 53″: And from thence its Motion begins to be to the West, till the Sun arrives at the 10*th* of the *Scorpion*; and thereabouts it changes its Course and goes Eastward. It is plain, that when the Points A and *m* coincide, that there the mean and *Apparent Time* must likewise coincide. Hence if we have a Pendulum Clock accurately and nicely fitted, and the Motion of the Hand set to equal or *True Time*, the Hand of this Clock will always point out the *Time* different from the Solar *Time* shewed by a Sun-Dial; except four times a Year, which is about the 4*th* of *April*, the 6*th* of *June*, the 20*th* of *August*, and the 13*th* of *December*. At all other Times the Hour by the Sun-Dial will either be before or later than that shewed by the Hand of the Clock: And about the 23*d* of *October* the Clock will differ most of all from the Sun, where its Motion is slower than the Solar *Time* by 16′. 11″.

IF you inquire in what Points the *Equations* are the greatest, the eminent Dr. *Edmund Halley*, who for his great Inventions is never to be mentioned by *Astronomers* without Honour, has given us the Solution of this *Problem*. But to understand it we must first lay down the following *Lemma*.

LEMMA.

IF any plain Figure be projected Orthographically on a Plane; which is done by letting fall from every point of it Perpendiculars on the Plane of Projection; the Area of that Projection of the Figure will

will be to the Figure projected, as the Co-sine of the Inclination of the Planes is to the Radius.

FOR any Figure can always be resolved into Parallelograms or Triangles, whose Bases are parallel to the common Section of the Planes; and therefore they will be parallel to the Plane on which they are projected: Wherefore the Bases of these Parallelograms or Triangles, and their Projections on the Plane, are always equal to each other, and parallel, as we have shewed in *Lecture* XIII. But the Perpendiculars let fall from the Summits or Tops of the Triangles and Parallelograms upon the Bases, are also perpendicular to the common Section of the Planes, by the 29*th* of the first *El.* And therefore the Inclination of the Perpendiculars to the Plane is equal to the Inclination of the Planes to each other. And consequently, the Projections of these Perpendiculars will be to the Perpendiculars themselves, as the Co-sine of the Inclination of the Plane is to the Radius. Wherefore every Parallelogram or Triangle is projected into another, whose Base is equal to the Base of the Triangle or Parallelogram projected; and its height is to the height of the Figure projected as the Cosine of the Inclination of the Planes is to the Radius. But Triangles and Parallelograms whose Bases are equal, are as the Perpendiculars let fall from the Tops upon the Bases. The Projection therefore of each Triangle is to the Triangle projected in a constant and given proportion; consequently all the Projections of all the Triangles or Parallelograms are to the Figures projected in the same Proportion; that is, the Projection is to the Figure projected as the Co-sine of the Inclination is to the Radius.

IF the Orbit of the Earth be Orthographically projected on the Plane of the Equator, by letting fall from each of its Points Perpendiculars, the Projection will be an Ellipse, in whose Perimeter the Extremity of a Right Line let fall from the Earth, perpendicular to the Plane of

Lecture XXV. the Equator, will conſtantly move: And this point by its Motion will mark out the Right-Aſcenſion of the Earth, or its Motion according to the Equator, as it is to be ſeen from the Sun; to which the Right-Aſcenſion of the Sun ſeen from the Earth is always equal. Let ♈ A ♎ C be the Ellipſe in which the Orbit of the Earth is projected, S the point of Projection of the Sun's Center, ♈ S ♎ the common Interſection of the Equator and the Ecliptick, A any point, where a Perpendicular from the Earth meets with the Projection: The Angle ♈ S A, will meaſure the Right-Aſcenſion of the Sun. Now I ſay that this point A which marks out the Motion of Right-Aſcenſion, will ſo proceed in the Ellipſe ♈ A ♎ C, that it will deſcribe about the point S Elliptick Area's proportional to the Times. For in a given Time let A move thro' the Elliptick Arch A B; draw the Lines A S and B S; and the trilinear Figure A S B will be the Projection of the correſpondent Area which the Earth deſcribes in the Plane of the Ecliptick, in the ſame Time, round the Sun: And therefore the Projection A S B will be to the correſpondent Area in the Earth's Elliptick Orbit, as the Co-ſine of the Inclination of the Equator and the Ecliptick is to the Radius. But in the ſame Proportion is the whole Elliptick Area ♈ A ♎ C to the whole Area of the Earth's Orbit: Therefore by Permutation of Proportion, the trilineal Figure A S B will be to the whole Elliptick Area ♈ A ♎ C, as the Area deſcribed in the Earth's Orbit round the Sun is to the whole Area of the Earth's Orbit; that is as the Time in which that Area in the Orbit of the Earth, or the Area A S B in the Projection, is deſcribed, is to the whole Periodical Time. Therefore the point A moves in the Perimeter of the Ellipſe at ſuch a rate, that it deſcribes about S Area's that are continually proportional to the Times.

Plate XXIV. Fig. 5.

THE ſame things being laid down; at the Center S and diſtance S A, which is a mean

propor-

proportional between half the greater and half the lesser Axis of the Ellipse, describe a Circle; this Circle will be equal to the whole Elliptick Area; as it is easy to demonstrate from the Doctrine of the *Conick Sections*: This Circle will cut the Ellipsis in four Points E, F, G, H. The points of Intersection shew the Right-Ascensions of the Sun, where the Equations are greatest. Imagine a point M to move uniformly in the Periphery of the Circle; its Motion will then represent the Motion of our imaginary Star *m*, and will describe about the point S circular Sectors that are proportional to the Time: And because the Area of the whole Circle and the Area of the Ellipse are equal, the Area's of the Elliptick Sectors and of the Circular Sectors, described in the same time, will be constantly equal. Let us now suppose that the point M in the Periphery of the Circle, and the point that marks out the Sun's Right-Ascension in the Ellipse, be placed at the same time both in the right Line S L M. Let these Points afterwards be in *m* and A, then the Elliptick Area L S A will be equal to the circular Sector M S *m*: And because the Arch M *m* is without the Ellipse, the Angle M S *m* will be less than the Angle M S A, and the difference of the Angles measured by the Arch *m* A, which is the *Equation of Time*. When the point which marks out the Right Ascension of the Sun comes to the Intersection F of the Circle and Ellipse; there its angular Motion round the Sun will be equal to the angular Motion of the point *m*; for the Area's *m* S *n* and A S F are equal, they being both described in the same Moment of Time, and at the same distance from S; and consequently the Arch *q* F is equal to the Arch *m n*. In the point therefore F, the Motion of Right-Ascension is equal to the Motion of the imaginary Star, or equal to the mean Motion. The same thing may be shewed at G, H and E: But it was shewed before, that where the Motion of Right-Ascension

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Plate XXIV. Fig. 6.

 was

Lecture XXV. was equal to the Motion of the point *m*, that there the Equations are greateſt. Wherefore in the points F, G, H and E are the Equations greateſt.

Which are the points of the Eclip-tick where the Days are longeſt and where ſhorteſt.

IF you inquire in what points the Days are longeſt or ſhorteſt, the ſame eminent Dr. *Halley* has alſo given us a Geometrical Solution of this *Problem.* Let ♈ ♋ ♎ ♑ be the Ellipſe into which the Earth's Orbit is projected, and S the point of the Sun's Center, K the Center of the Ellipſe. Produce K S on each hand, ſo that K G and S H may be to K S (which is the Projection of the Eccentricity) as the ſquare of the Radius is to the ſquare of the Sine of the Obliquity of the Eclipttick: Thro' K draw ♈ ♎ parallel to the common Section of the Equator and Eclipttick, and cut it at Right-Angles with the Line ♋ K ♑: Thro' G draw G F, and thro' H draw F H parallel to the Lines ♋ ♑ and ♈ ♎; and thro' S and K deſcribe the Hyperbola A B whoſe Aſymptots are F G, F H. This Hyperbola and its oppoſite C D will cut the Ellipſe in the points that are required; that is, when the Sun is in the points of the Eclipttick which correſpond with B and D, then the Days are the longeſt; and in B the Days are longer than in D: But the points of the Eclipttick which anſwer to A and C, give us the places where the Days are ſhorteſt. The Demonſtration of this depends on the Motion of the point that marks the Right-Aſcenſion of the Sun round S; for it deſcribes about it Area's that are proportional to the Times. Therefore the angular Velocity is every where reciprocally as the ſquare of the diſtance from S; conſequently the Velocities muſt be greateſt where theſe diſtances are leaſt; that is, where the leaſt Lines that can be drawn from S fall upon the Ellipſe; and the Velocities are the leaſt where the Lines drawn from S to the Ellipſe are the greateſt: But by the Conſtruction, and the *62d Prop. Lib.* V. of *Apollonius*'s *Conicks*, it is evident that the Hyperbola's will cut the Ellipſis in the points A and

Plate XXIV. Fig. 7.

and C; where the Right Lines S A and S C are the greateſt; and in the points B and D, where the Right Lines S B and S D are the leaſt: For in theſe points the Lines S A, S B, S C, S D are perpendicular to the Curve. Hence the Motion of the Sun, according to his Right-Aſcenſion, will be quickeſt in B and D; and therefore the Days will be then the longeſt: And the Motion being ſloweſt in C and A, the Days will be there the ſhorteſt.

LECTURE XXVI.

Of the Theories of the other Planets.

AFTER having explained the Theory of the Earth's annual Motion, and ſhewed the Methods by which the Form of its Orbit, and the Poſition of the *Apſides* are determined, we may then by the help of *Aſtronomical* Tables compute for any time the place of the Earth in the Ecliptick ſeen from the Sun, and its oppoſite point in which the Sun appears to be, as he is obſerved by us. We will now come to explain the Theories of the other Planets, the knowledge of which cannot be attained without the Earth's Motion being perfectly known.

The Heliocentrick and Geocentrick place of a Planet that is in Oppoſition to the Sun coincide.

BUT the Periods of the Planets or the Times they take to compleat their Circulations are to be found out in the firſt place. For which purpoſe we muſt obſerve, that when any ſuperior Planet comes to an Oppoſition with the Sun,

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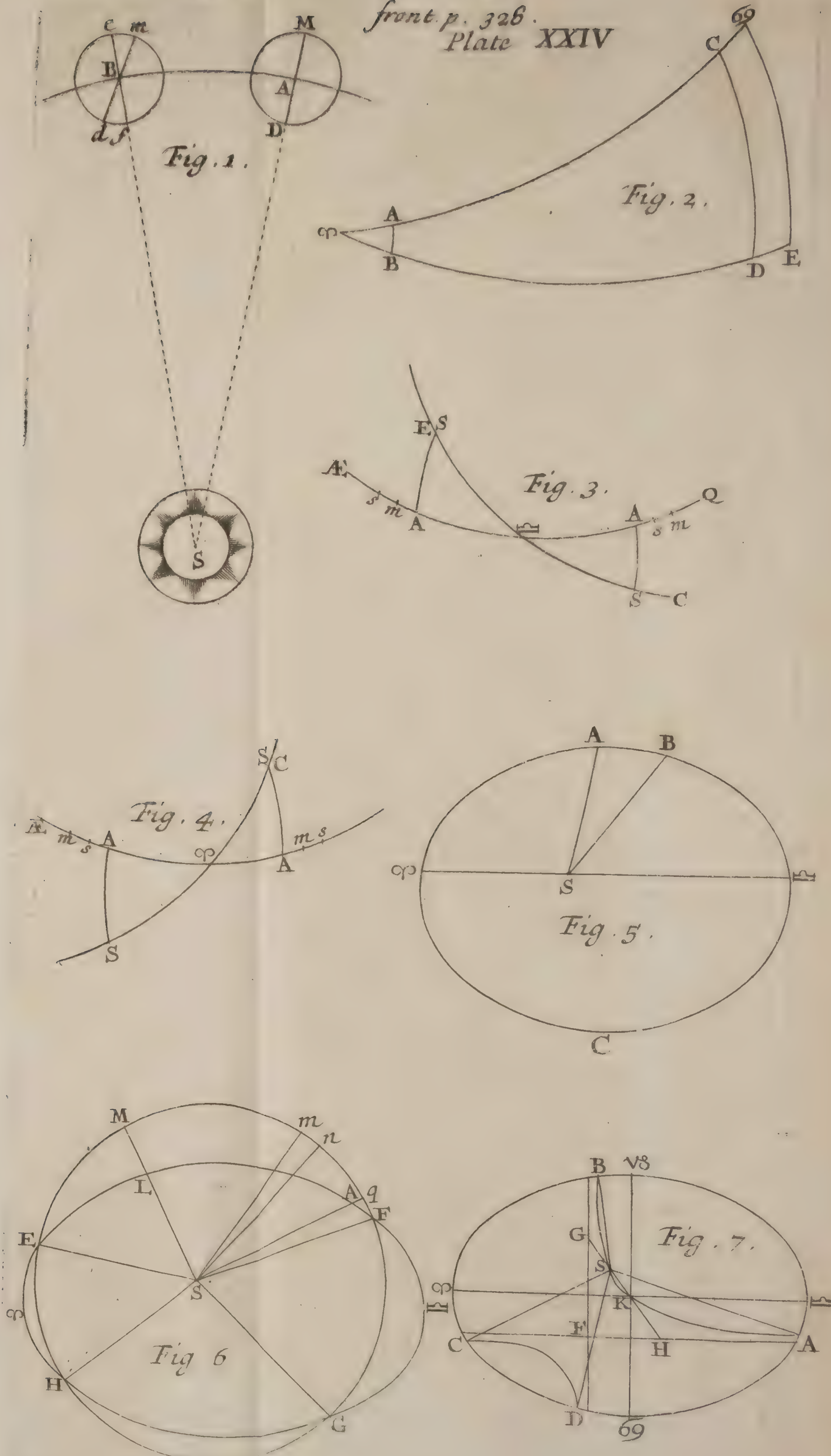
Sun, they then appear in the ſame point of the Ecliptick ſeen from the Earth, as they would do if the Eye were in the Sun and obſerved them from thence; as alſo the inferiour Planets when they are in Conjunction with the Sun, and are obſerved in the Sun's Disk: If there were an Obſerver in the Sun, he would ſee them in the oppoſite point of the Ecliptick in which we behold them: And therefore when ever a ſuperiour Planet is in Oppoſition to the Sun, his Heliocentrick and Geocentrick places coincide: But when an inferior Planet is in Conjunction with the Sun, and is ſeen in his Disk, the Heliocentrick and Geocentrick Places are oppoſite to each other. Moreover in the inferiour Planets, when they are at their greateſt Elongations from the Sun, the Angle at the Sun's Center, contained between the Right Lines drawn to the Earth and Planet, is nearly the Complement of the Elongation: For in Orbits which are nearly circular, a Line touching the Orbit is almoſt perpendicular to the Line drawn from the Sun to the point of Contact: And therefore that Angle will be given. But we have the point of the Ecliptick in which the Earth is at that time ſeen from the Sun; and conſequently the point of the Ecliptick in which the Planet is ſeen from the Sun. And therefore in theſe Poſitions we have the Heliocentrick places of the Planets.

How to find nearly the Periodical Time of a Planet.

IF then any ſuperiour Planet, as for Example, *Jupiter* were obſerved when he is in Oppoſition to the Sun: And again, if he were likewiſe obſerved when he comes next in Oppoſition to the Sun, we ſhall have that Arch which the Planet ſeen from the Sun has in the mean time deſcribed. Say as that Arch is to the whole Circumference, ſo is the time between the Obſervations to a fourth, which will be nearly the Periodical Time of the Planet. After the ſame manner, by obſerving two Heliocentrick places of an inferiour Planet, we may nearly collect its Periodical Time. I ſay nearly, and not exactly; for the

front. p. 328.
Plate XXIV



the Calculation supposes that the Motion of the Planet is in a Circle, and that thro' the whole Period it is uniform, which is not true.

Lecture XXVI.

A more accurate Method of finding the same.

THE following Method for finding the Periodical Times is more accurate. Observe a Planet twice successively in the same Node; that is, let there be two Observations, when the Planet about the same part of its Orbit has no Latitude; which can only happen when the Planet has really no Latitude, and is placed in its Node: The Time between the two Observations will be equal to the Periodical Time of the Planet. For because all the Planets move in Orbits whose Planes are different from the Plane of the Ecliptick, and the Sun is in the common *Focus* of all the Orbits, these Planes will all cut the Ecliptick in Lines which pass thro' the Sun, and in the Intersections of these Lines with the Ecliptick are the Nodes; and the Planet in the whole time of its Period can never be observed but once in one and the same Node. Now the Nodes are either at rest, or they have a very slow Motion, so that for the space of one Period they may be esteemed as at rest. And therefore if we know the time between two arrivals of a Planet at the same Node immediately following each other, we shall likewise know the time of a Planet's Period.

BY the very same Observations, if we have the Theory of the Earth's Motion, we can find the Position of the Line of the Nodes or the points of the Ecliptick, in which that Line does intersect it. Let ATB be the Orbit of the Earth, CND the Orbit of the Planet, NS*n* the Line of the Nodes; and in the first Observation suppose the Earth in T, and the Planet to be observed in N: And because the place of the Planet seen from the Earth is known by Observation, and the apparent place of the Sun, at the Time, is known by the Theory of the Earth's Motion; we have the Arch of the Ecliptick between the two places, or the measure of the Angle NTS. In the

Table XXV. Fig. 1.

Lecture XXIV. the second Observation let the Earth be in t, and the Planet in the same Node N, and we shall have by the same way the Angle N t S. In the right-lin'd Triangle T S t we have the sides T S, t S, and the Angle T S t, which is known by the Theory of the Earth; therefore by *Trigonometry* we can find the Angles S T t and S t T, as likewise the side t T: Therefore from the known Angle S T t take away the known Angle S T N, and we shall have the Angle N T t. To the known Angle n t S add the Angle S t T, which was found out, and we have the Angle N t T. Then in the Triangle N t T we have all the Angles and the side t T; consequently we shall have the side N T, the distance of the Planet from the Earth at the first Observation. Lastly, in the Triangle N T S we have the sides N T and T S, and the Angle N T S which was known by Observation; consequently we shall find the side N S the distance of the Planet from the Sun when he is in the Node, and the Angle T S N, which shews the Position of the Line of the Nodes; for that point of the Ecliptick which the Earth is in, seen from the Sun at the time of the Observation, is known; and the Angle T S N is likewise known: Therefore we have the point of the Ecliptick N, in which the Node is placed seen from the Sun; and the point n opposite to it will be the place of the other Node. And therefore the Position of the Nodes is found.

How to find the Position of the Nodes.

To find the Inclination of the Planet's Orb to the Ecliptick.

Plate XXV. Fig. 2.

THE Places of the *Nodes* being once determined, we shall easily find the Inclination of the Plane of the Planets Orbit to the Ecliptick: For having the Places of the *Nodes*, we can find the Time when the Earth seen from the Sun is in one of them. At the same Time observe the *Geocentrick* Latitude of the Planet, and his distance from the opposite *Node*: Then the *Geocentrick* Latitude of the Planet is equal to the *Heliocentrick* Latitude it will have, when seen from the Sun at the same distance from the *Node*; that is, make the Angle n S p equal to the Angle n N P, and the

Lati-

Latitude of the Planet at *p* obſerved from S, will be equal to its Latitude at P obſerved from N. For let CPD be the Orbit of the Planet, NS*n* the Line of the *Nodes*, BNT a Portion of the Orbit of the Earth, in which ſuppoſe the Earth to be at N in the Line of the *Nodes*, and the Planet in its Orbit to be at P; and then the Sun, Earth and Planet will be all in the Plane of the Planet's Orbit. From the Point P on the Eclipt ick's Plane let fall the Perpendicular PE, and in the Plane of the Ecliptick draw the Line NE; then the Plane of the Triangle NPE will be Perpendicular to the Ecliptick, and the Angle PNE will be the viſible Latitude of the Planet ſeen from the Earth. Through S draw S*pf* parallel to NP, and *pe* parallel to PE; and the Plane through S*p* and *pe* will be parallel to the Plane NPE, and conſequently perpendicular to the Plane of the Ecliptick; and therefore S*e* the common Section of the Ecliptick with this Plane will be parallel to NE. And becauſe NP and NE are parallel to S*p* and S*e*, the Angle *p*S*e* the *Heliocentrick* Latitude, will be equal to the Angle PNE the Latitude of the Planet obſerved from the Earth in the *Node* N.

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LET *nf* be a Portion of the Planet's Orbit extended to the Heavens, *nh* a Portion of the Ecliptick, *fh* a Circle of Latitude paſſing through the *Heliocentrick* place of the Planet. In the Right Angled Spherical Triangle *nfh*, having *nh* the diſtance of the Planet from the *Node*, equal to what was obſerved when the Earth was at N, and the Latitude *fh* equal alſo to what was obſerved at N, we can find from thence the Angle *hnf* the Inclination of the Plane of the Orbit to the Ecliptick, which was to be found out.

HAVING once found out this Inclination, by Obſervation we can find out the *Heliocentrick* place of the Planet, and his diſtance from the Sun, when ever he comes in oppoſition to the Sun.

LET

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How to find the Heliocentrick place and distance from the Sun when the Planet is in opposition to the Sun.

Plate XXV. Fig. 3.

LET A T B be the Orbit of the Earth, D P E the Orbit of the Planet: Suppose the Planet in P, and the Earth in T, and N S *n* the Line of *Nodes*, in which the Sun is in S. The Planet being in opposition to the Sun, its place reduced to the Ecliptick, will be in the Line S T, which passes through the Earth. Observe the Angle P T E the Planets *Geocentrick* Latitude, and we have the Angle P S T his *Heliocentrick* Latitude, because we have the Planet's distance from the *Node*. Likewise by the Theory of the Earth's Motion, we have S T its distance from the Sun. And therefore in the Triangle P S T, having all the Angles and one Side ST, we shall find SP the distance of the Planet from the Sun; and the Angle P S *n* the distance of the Planet from the *Node*, is found by the *Heliocentrick* Latitude, by which means we have the place of the Planet in his own Orbit. In the same manner if we have any other two Observations of the same Planet, in a Position or Aspect opposite to the Sun, we shall have the Position and Magnitude of three Lines, through whose Extremities the Planet's Orb passes, and the Sun is in one of the *Foci* of the Orbit. And therefore to determine this Orbit, its Form and Position, we must describe an Ellipse whose *Focus* is given, and which will pass through three given Points. The *Geometers* shew the Method of constructing this Problem, and we will likewise give the Solution of it hereafter.

To find the Heliocentrick place and distance when the Planet is in any other Aspect.

Plate XXV. Fig. 4.

THOUGH a Planet were not in an Acronychal Position, but in any other Aspect besides an Opposition to the Sun, yet by one Observation its distance from the Sun and *Heliocentrick* place may be found. Suppose P A E the Orbit of the Planet, TGH the Orbit of the Earth. Let the Earth be in T, and the Planet in P, and the Sun in S in the Line of the *Nodes* N S. From P let fall the Perpendicular P B on the Plane of the Ecliptick: Draw B T, and produce it till it meets with the Line of the *Nodes* in N, and the Plane of the Triangle N P B will be perpendicular to the Plane of the Ecliptick. Let the Line C T be also per-

pendicular

pendicular to it, and meet with the Plane of the Planet's Orb in C. From T upon the Line S N let fall the Perpendicular T D; joyn the points D and C, and the Angle T D C will be the Inclination of the Planet's Orbit to the Ecliptick, which Angle is therefore given. Observe the Angle B T P the Planet's *Geocentrick* Latitude, and the Angle B T S its Elongation from the Sun according to the Ecliptick. In the Triangle N T S, from the Theory of the Earth we have the side S T the distance of the Earth from the Sun, and the Angle T S N, which is known by the place of the Earth and *Node* in the Ecliptick, as also the Angle S T N the Complement of the Angle S T B to two Right Angles: hence we shall have NT. In the Right Angled Triangle T S D, having T S and the Angle T S D, we shall find T D; and therefore in the Right Angled Triangle TDC, having TD and the Angle T D C the Inclination of the Orbit to the Ecliptick, we shall find the side TC. In the Right-Angled Triangle TCN we have TC and N T, and therefore we can find the Angle T N C. And again, in the Triangle N T P, we have all the Angles; for the Angle N T P is the Latitude of the Planet found by observation, or its complement to two Right-Angles, and the Angle P N T just now found, as also the side N T, wherefore we shall find the side T P. In the Triangle PTB rectangular at B, we have the side T P, and the Angle P T B, which is the Latitude observed; wherefore we shall have the sides B T and B P. And in the Triangle TSB, having T B and T S, and the Angle B T S, we shall have the side S B, which is called the *Curtate distance* of the Planet from the Sun, as also the Angle T S B, and consequently the *Heliocentrick* place of the Planet reduced to the Ecliptick. Lastly, in the Triangle PBS, we have the sides PB, BS, and by them we shall have SP the distance of the Planet from the Sun, and the Angle PSB the *Heliocentrick* Latitude of the Planet. But having the *Heliocentrick*

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centrick

Lecture XXV. *centrick* Latitude and the Inclination of the Planetary Orbit to the Ecliptick, we can find the Planet's diſtance from the *Node*, and conſequently his diſtance from the *Node* in his proper Orbit, and his Centrick place ſeen from the Sun. If by this Method we find out two other *Heliocentrick* places of the Planet and the diſtances from the Sun, having likewiſe the *Focus* of the Orbit which is the Center of the Sun, we may deſcribe an Ellipſe which ſhall paſs through the given points, and be the Orbit of the Planet.

Dr. Halley*s Method of determining the* Helio-centrick *place and diſtance from the Sun.* Plate XXV. Fig. 5.

THE moſt Ingenious Dr. *Halley* contrived another Method for finding out the Centrical places of the Planet, and its diſtances from the Sun, which ſuppoſes only that the Periodical time of the Planet is known. Let K L B be the Orbit of the Earth, S the Sun, P the Planet, or rather the point in the Plane of the Ecliptick on which the Perpendicular let fall from the Planet meets that Plane. And firſt when the Earth is in K, obſerve the *Geocentrick* Longitude of the Planet, and having the Theory of the Earth, we have the Apparent Longitude of the Sun; wherefore we have the Angle PKS. The Planet after it has compleated an intire Revolution, does again return to the ſame point P, at which time ſuppoſe the Earth in L, and there again let the Planet be obſerved, and find the Angle PLS, the Elongation of the Planet from the Sun. Having the times of the Obſervations, we have the places of the Earth in the Ecliptick, or the points K and L, and conſequently the Angle LSK, and the ſides LS and SK; wherefore we ſhall have the Angles SKL and SLK, and the ſide LK. From the known Angles SKP and SLP, take away the known Angles SKL and SLK, and we ſhall have the Angles PKL and PLK known; therefore in the Triangle PLK, having all the three Angles, and the ſide LK, we ſhall find the ſide PL; And in the Triangle PLS, having the ſides PL and LS and the intercepted Angle PLS, we ſhall

ſhall have the Angle LSP, which determines the *Heliocentrick* place, and its diſtance from the *Node* according to the Ecliptick, as alſo the ſide SP. But as the Tangent of the *Geocentrick* Latitude is to the Tangent of the *Heliocentrick*, ſo is the *Curtate diſtance* of the Planet from the Sun, to its *Curtate diſtance* from the Earth. But by Obſervation we have the Planet's *Geocentrick* Latitude, wherefore its *Heliocentrick* Latitude will alſo be found. By which and the *Curtate diſtance* of the Planet from the Sun, we can find out the true diſtance which was wanted. If by this means we acquire three *Heliocentrick* places of the Planet, and the correſpondent diſtances from the Sun, we ſhall have the Form of the Orbit, and the Poſition of the *Apſides*, by deſcribing an Ellipſe which ſhall paſs through three given points. This *Ellipſis* is determined by the following Method.

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To deſcribe a Planet's Orbit or to find its Poſition and Eccentricity Plate XXV. Fig. 6.

LET SD, SC and SB, be three Lines given in Magnitude and Poſition. Draw DC and BC and produce them, ſo that DF may be to CF as DS is to CS; and alſo CE to BE, as CS is to BS. Joyn FE, on which from S let fall the perpendicular SG, which will give the Poſition of the Axis. Draw the Lines DK, C*i* and BH; and cut SG in A, and produce it, ſo that GA may be to SA, as KD is to SD, and alſo G*a* be to S*a* in the ſame proportion; and make *sa* equal to SA. And the points A and *a* are the *Vertices* or *Apſides* of the Orbit, whoſe *Foci* are S and *s*, and greater Axis A*a*; and if with theſe *Apſides* and *Foci* we deſcribe an Ellipſe, it will be of the ſame Form with the Orbit of the Planet. For becauſe SD is to CS as FD is to FC, and ſo DK is to C*i*; by change of proportion, DS is to DK as CS is to C*i*, and ſo is SB to BH. But as DS is to DK, ſo by conſtruction is SA to GA, and S*a* to G*a*; therefore as $SA:GA::Sa - sa$ or $Ss:aG - AG$, or A*a*. And therefore we have $SD:DK::SC:Ci::SB:BH::Ss:Aa$. But this is the Property

Lecture XXVI. perty of an Ellipse whose *Focus* is S, and greater Axis A *a*, as is demonstrated by the Writers of Conicks, and particularly by Mr. *Milnes* in his Treatise of *Conick Sections*, Part IV. *Prop.* 9. It is evident therefore that the Ellipse described with the *Foci* S, *s* and Axis A *a* will pass thro' the points B C and D.

BECAUSE in *Astronomy* a Calculation is always preferable and more useful than the neatest Construction, the Form and Position of the Ellipse is in this manner found out by Computation. In the Triangle D S C having the sides D S and C S and the Angle D S C, we can find out the side D C with the Angles S C D and S D C; and in the same manner we can find in the Triangle B S C the side B C and the Angles S B C and S C B: And because we have the *Ratio* of D F to C F and we have D C, we shall also have C F. In like manner, because we have the *Ratio* of C E to B E and we have B C, we shall have C E and B E. But we have the Angle B C D equal to the Sum of two known Angles, and therefore we have the Angle F C E its Complement to two Right-Angles. In the Triangle F C E we have the sides F C and C E, and the Angle F C E, wherefore we can find the Angle F E C, and its Complement to a Right the Angle *i* C E, to which adding the known Angle S C B, we have the whole Angle S C *i*: And because S *a* and C *i* are parallel, the Angle C S *a* is equal to the Angle S C *i*: Having therefore the Angle C S *a* we have the Position of the Axis. In the Right-angled Triangle E C *i*, having E C and the Angle E, we can find C *i*; and therefore we can find the proportion of C S to C *i*. In the Triangle C S L, Right-angled at L, we have the Angle C S L the Complement of the Angle C S *a* to two Right-Angles, and the side C S: Therefore we shall have S L, to which adding L G equal to C *i*, we have the whole S G: And because C S and C *i* are known, their proportion will be known:

As CS is to C*i*, ſo let SA be to AG, and ſo let S*a* be to *a*G, and ſo let S*s* be to A*a*, and we have the *Apſides* of the Ellipſe A and *a*, and its *Foci* S and *s*, which were to be found. Lecture XXVI.

WE ſhewed above, how by an Obſervation to find the *Heliocentrick* place of a Planet, and we have now ſhewed how to determine the Poſition of the *Aphelion*; by which means we can find the diſtance of a Planet from the *Aphelion*, at the time of the Obſervation; this diſtance from the *Aphelion* is called the *true* or *Co-equated* Anomaly of the Planet. But having the Eccentricity of the Orbit, and the Periodical Time, we ſhewed before how to find the Planet's mean Anomaly, in the *Lecture* in which we gave the Solution of *Kepler*'s Problem; therefore at the time of the Obſervation we ſhall have the Mean Anomaly of the Planet, or the place he would have in his Orbit, did he conſtantly proceed with the ſame Angular Motion round the Sun. This being once obtained we have the Planet's Mean Motion for any other time. For ſay, as the Periodical Time of the Planet is to the Time between the Obſervation and the Moment of Time for which the Mean place is deſired, ſo is 360 Degrees or a whole Circle to a fourth. This Arch, if the Time preceded the Obſervation, being ſubſtracted from the place before found, or added to it, if it comes after the Obſervation, will give the Mean place of the Planet for the Time propoſed.

How to find a Planet's Mean Anomaly.

FOR the more eaſily finding the Mean place of a Planet, for any Moment of Time, it will be eaſieſt to take out its Motion from the *Aſtronomical* Tables, in which is ſet down the Planet's Mean place or Mean Anomaly, in the beginning of any remarkable Æra; ſuch as is from the Birth of our Lord, the Æra of *Nabonaſſer*, of the Creation, the building of *Rome*, or the firſt Year of the *Julian* Period: the places of the Planets at theſe inſtants of Time, are found by the preceding Methods, and are computed ac-

The Radix or Epocha.

 cording

Lecture XXVI. cording to the *Meridian* of *Equal Time*, and no for the *Apparent Time*. The place for that Time is called the *Epocha* or *Radix*, that is, the Root, from which, as from an immoveable Foundation, all the Motions are Calculated.

How to Compute the Mean Anomaly.

IF the Times be Numbred by the Years from the Birth of *Christ*, or from the beginning of the *Julian* Period. It will be most convenient that the Year take its beginning from that Mid-day which preceded the first of *January*, so that at the Mid-day of the first of *January* there is one Day compleatly finished. Say, as the Periodical Time is to a common Year of 365 Days, so is a whole Circle or 360 Degrees to a fourth, which will be the Mean Motion of the Planet for one Year. In like manner say, as the Periodical Time is to a Day, so a whole Circle is to a fourth; and we shall have the Mean Anomaly pertaining to one Day. And by working with the like Proportion we shall have the Mean Anomaly for an Hour, and for every Minute and Second. And if we add the Motion for one Year continually to itself, we shall have the Motion in two, three and four Years: But because every fourth Year is *Bissextile*, and consists of 366 Days, to the Motion of the fourth Year we must add the Motion of one Day; then by constantly adding the Motion of one Year, we shall have the Motion of five, six and seven Years. But the Motion of the Eighth Year is to be increased by the Motion of one Day, or rather the Motion of four Years is to be doubled, to have the Motion of Eight Years; because that Year is *Bissextile*. From these Motions so collected by Addition, we must always reject the whole Circles or 360 Degrees, for after a Planet has compleated its Circle, it returns to the same place. By this Method we have the Mean place of the Planets to 20 Years; and if the Motion of 20 Years be constantly added to itself, we shall have the Mean place for 40, 60, 80 and 100 Years; and to each of them add the Motion of 10 Years,

and we have the Motions and places for 30, 50, 70 and 90 Years. And by the continual addition of the Motions of 100 Years, rejecting always whole Circles, we ſhall have the Motions of 200, 300, 400, 500, &c. Years, even to 1000: And proceeding in the ſame way, we ſhall have the Motion of 2000, 3000, 4000 and 5000 Years, and ſo as far as you will. Lecture XXVI.

THESE Motions being in this way computed, are to be diſpoſed in Tables, which are called Tables of the Mean Motion, or Mean Anomaly, when they are numbered from the *Aphelion*, and they are found in all the *Aſtronomical* Tables for each Planet. But if the Mean Motions are computed from the Equinoctial points, inſtead of the Periodical Time, you muſt take the time the Planet revolves in the *Zodiack*, which is ſomewhat leſs than the Periodical Time, becauſe of the Præceſſion of the Equinocties, by which the Interſection of thoſe Points meet the Planet. If the *Aphelia* of the Planet be ſuppoſed to move, this Motion muſt be conſidered, and the Motion of the Equinocties and of the *Aphelia* (which for ought we know are equal, but in the Moon) are likewiſe to be computed and diſpoſed in Tables for Years, Tens, Hundreds, and Thouſands of Years, as the other Mean Motions are; that for any Time we may have the places and diſtances of the *Aphelia* from the Equinocties.

THE *Aſtronomers* have ſome other Tables which give the true Anomalie anſwering to every Degree of Mean Anomaly, which are computed by ſome of the Methods delivered above in the former *Lectures*. If Minutes and Seconds are added to the Mean Motions, we muſt take the difference of the True Anomalies, which are one Degree diſtant from each other, and by proportioning, we muſt add that part which is to be added to the Tabular Anomaly which is next leaſt, or is to be ſubſtracted from it, if it be next greateſt.

FOR the Motions of the Sun and Moon, they commonly compute the Equations or *Proſthaphæreſis*,

Lecture XXVI. which are the differences between the true and mean Anomaly; and they, either ſubſtracted or added to the mean Anomaly, as the Planet is in the firſt or ſecond Semicircle of Anomaly, give the True.

The Argument of Latitude. HAVING the Places of the *Aphelion* and *Nodes*, we have their diſtance from each other: And therefore having the True Anomaly of the Planet, we have its diſtance from the *Node*, which is called the *Argument of Latitude*, by which, and an eaſy *Trigonometrical* Calculation, we can find the Centrical Latitude of the Planet, and its *Curtate diſtance* from the Sun, which is the diſtance from the Sun to that point, where a perpendicular let fall from the Planet meets with the Ecliptick. *The Curtate diſtance of a Planet.* And thus we have ſhewed how to find the Centrical place and Latitude of the Planet, and its *Curtate diſtance* from the Sun. After theſe are found, we ſhall likewiſe be able to find his *Geocentrick* place, or where he will be ſeen from the Earth, in the following Method.

FIND firſt the Planet's *Heliocentrick* place and *Curtate diſtance* from the Sun, as alſo the Earth's place and diſtance from the ſame. Let TCF be the Orbit of the Earth, in which the Earth is in T; APE the Orbit of the Planet, and its place P, the Sun S, *n* S N the Line of *Nodes*. From the place of the Planet let fall on the Plane of the Ecliptick the right Line PB; draw SB and produce it till it meet with the Ecliptick in the Planet's place reduced to the Ecliptick, which place is found by the Arch PN and the Inclination of the Orbit to the Plane of the Ecliptick, which are known: But we have the place of the Earth ſeen from the Sun; and therefore we have the diſtance between them, or the Angle TSB, which is called *the Angle of Commutation*. *The Angle of Commutation.* Then in the Triangle STB, we have ST the diſtance of the Earth from the Sun, and SB the *Curtate diſtance* of the Planet; wherefore we ſhall find the Angle STB the Elongation of the Planet from the Sun, or the Arch of the Ecliptick intercepted between the Sun's place and the

Planet's

Planet's place reduced to the Ecliptick; as alſo TB, the curtate diſtance of the Planet from the Earth. But the place of the Sun is given, for it is oppoſite to the place of the Earth ſeen from the Sun: Wherefore alſo we ſhall have the place of the Planet in the Ecliptick as it is ſeen from the Earth. Moreover, in the two Triangles PSB and TPB that are rectangular at B, the Tangent of the Angle PSB is to the Tangent of the Angle PTB, as TB is to SB: But as TB is to SB, ſo is the Sine of TSB the Sine of the Commutation, to the Sine of the Elongation STB. Wherefore ſay as the Sine of the Commutation is to the Sine of the Elongation, ſo is the Tangent of the Heliocentrick Latitude to the Tangent of the Geocentrick Latitude, which was to be found. And by theſe means the *Aſtronomers* are able to find, for any inſtant of Time, the Geocentrick place and Latitude of any Planet.

Lecture XXVI.

How to compute the Planet's Geocentrick place.

Plate XXVI. Fig. 1.

The Harmony between the Periods and Diſtances of the Planets.

COMPARING the diſtances of the Planets from the Sun with the Times of the Periods round him, we find that they all obſerve a wonderful regular and elegant Harmony and Law, *viz.*

THE *ſquares of the Periodical Times are in all of them proportional to the Cubes of their mean diſtances from the Sun.* Now their Periods and mean diſtances are theſe, which we here give in the following Table.

	The Periods. D.	h.	′	″	Mean Diſtances.
♄	10759	6	36	26	953800
♃	4332	12	20	35	520110
♂	686	23	27	30	152369
☉	365	6	9	30	100000
♀	224	16	49	24	72333
☿	87	23	15	53	38710

THE illuſtrious Mathematician Mr. *Hugens*, has determined very nicely the Diameters of the Pla-

Lecture XXVI. Planets, by comparing them with that of the Sun, in his *Saturnian System*, which he did by the following Method.

COPERNICUS by his New and divinely invented Syſtem, has ſhewed us how to find out the diſtance of each Planet from the Sun, in proportion to the Earth's diſtance from the ſame: But their apparent Diameters, and how much ſome are bigger than others, has been diſcovered by the help of the Teleſcope. For by comparing the proportions of their diſtances and apparent Magnitudes, the proportion of their true bigneſs to that of the Sun will eaſily be found, by the Principles we have layed down in our firſt *Lecture*.

The Diameters and Magnitudes of the Planets eſtimated.

AS for *Saturn*, the Diameter of his Ring, when he is neareſt to us, ſubtends an Angle of 68 Seconds: And becauſe this leaſt diſtance of *Saturn* is near eight times the mean diſtance of the Sun from us. It follows, that if *Saturn* were as near us as the Sun is, the Diameter of the Ring would appear eight times bigger than now it does, that is, it would be 9′. 4″. But the Diameter of the Sun in his mean diſtance is 30′. 30″. Therefore the proportion of the Diameter of the Ring to the Diameter of the Sun, is that of 9′. 4″. to 30′. 30″; which is near the proportion of 11 to 37. But the Diameter of *Saturn*'s body is to the Diameter of the Ring as 4 to 9; that is nearly as 5 to 11: And therefore it is to the Diameter of the Sun as 5 to 37.

JUPITER's Diameter, when he is next to us, is 64 Seconds; and then his diſtance is to the mean diſtance of the Sun as 26 to 5; ſay as 5 is to 26, ſo is 64 Seconds to a fourth, which will be 5′. 35″; which is the bigneſs of the Angle that *Jupiter's* Diameter would ſubtend, were he as near as the Sun is: But the Sun is ſeen under an Angle of 30′. 30″. Therefore the proportion of *Jupiter's* Diameter to that of the Sun is as 5′. 35″ to 30′. 30″; that is a little more than 1 to $5\frac{1}{2}$.

VENUS,

Plate XXV

front. p. 342

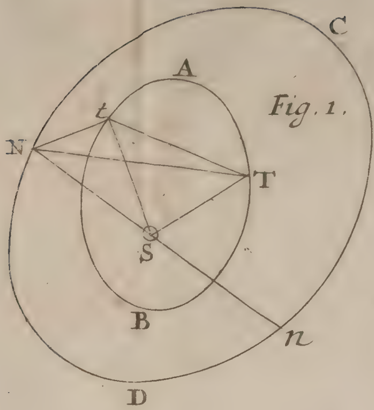

Fig. 1.

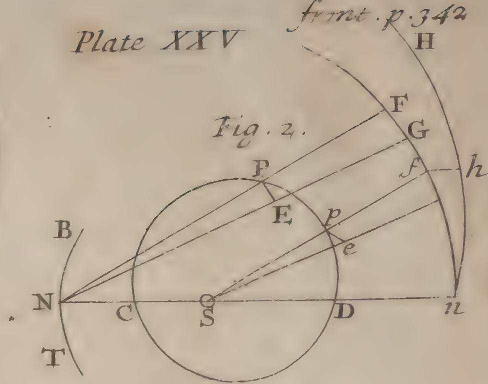

Fig. 2.

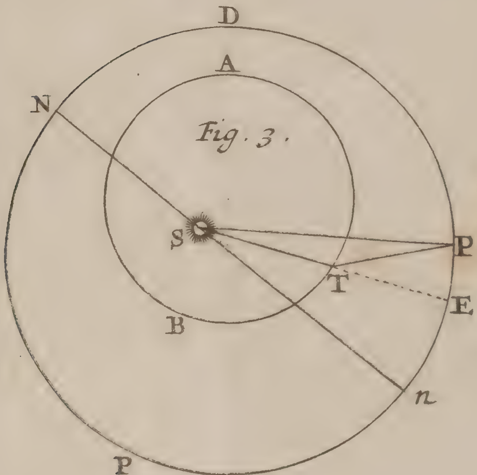

Fig. 3.

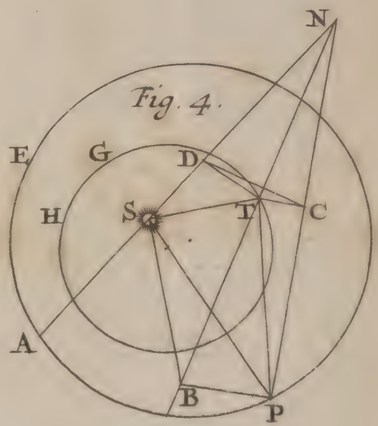

Fig. 4.

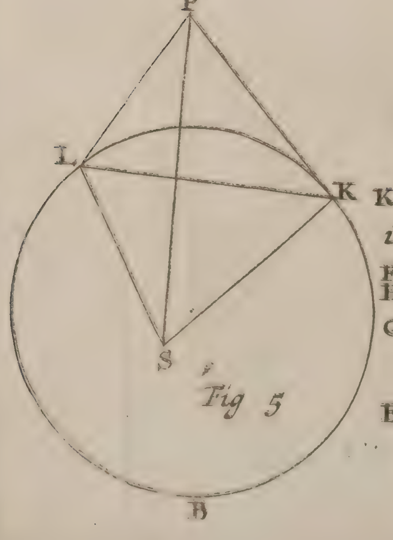

Fig 5

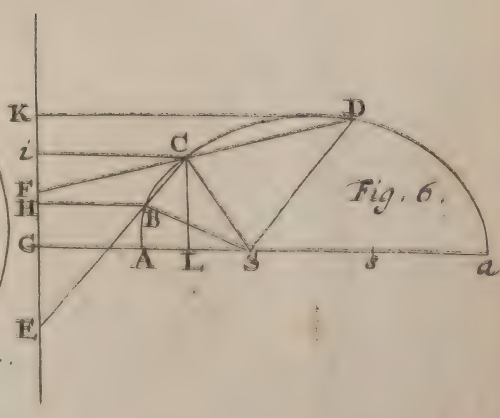

Fig. 6.

VENUS, when ſhe is neareſt the Earth, ſubtends an Angle of 85 Seconds; and then her *Perigæon* diſtance is to the mean diſtance of the Sun nearly, as 21 is to 82: And therefore if *Venus* were removed to the diſtance of the Sun, her Diameter would be only 21″. 46‴: And therefore we know that the Diameter of *Venus* is to that of the Sun as 21″. 46‴ to 30½′; that is as 1 to 84. Lecture XXVI.

BUT the Diameter of *Mars*, when neareſt to the *Earth*, is not greater than 30″: And therefore ſince the leaſt diſtance of *Mars* is to the Sun's mean diſtance as 15 to 41; the proportion of *Mars*'s Diameter will be to the Sun's Diameter as 1 is to 166: Therefore *Mars* is but half the bigneſs of *Venus* in its Diameter. *Hevelius* by Obſervations found that *Mercury*'s Diameter was to that of the Sun as 1 is to 290.

THE Magnitude of the Earth in compariſon of that of the Sun is variouſly eſtimated by the *Aſtronomers*: They who ſuppoſe the horizontal Parallax of the Sun to be 15 Seconds, muſt make the diſtance of the Sun from us to be but 13750 Semidiameters of the Earth; and the Diameter of the Earth will be to the Diameter of the Sun as 1 to 61: But we have a probable Argument which proves the Diſproportion or Inequality greater. For becauſe the Diameter of the Moon is ſomewhat more than a fourth part of the Diameter of the Earth; if the Parallax of the Sun were 15 Seconds, then the body of the Moon would be greater than that of *Mercury*; but it ſeems incongruous, that a ſecondary Planet ſhould be greater than a primary Planet. Let us ſuppoſe therefore that the Semidiameter of the Earth ſeen from the Sun be 11 Seconds, as it was lately collected from the Parallax of *Mars*, obſerved by Dr. *Halley* and Mr. *Pound*: And then the Earth's diſtance will be nearly 20000 Semidiameters of the Earth, and the Moon will be leſs than *Mercury*. And the Proportion of the Diameter of the Earth to the

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Sun will be that of 1 to 83; to which Proportion we may give our Assent, 'till by an Observation of *Venus* in the Sun's Body, which will happen in 1761, we may be made more certain of the Sun's Parallax. Therefore the Diameter of the Sun is to the Planet's Diameters, nearly in the proportions represented in the following Table.

The Diameter of the Sun is to the Diameter of	*Saturn*	as 1000 is to	137
	Jupiter		181
	Mars		6
	the Earth		12
	Venus		12
	Mercury		4

AND because Spheres are to one another as the Cubes of their Diameters,

The Sun will be to	*Saturn*	as 1000000000 is to	2571353
	Jupiter		5929741
	Mars		216
	the Earth		1728
	Venus		1728
	Mercury		64

HENCE it follows, that the Sun is a hundred and sixteen times bigger than all the Planets put together. *Saturn* is 400 times less than the Sun: But for quantity of Matter it is 2400 times less than the Matter of the Sun. *Jupiter*, the biggest of all the Planets, is 160 times less than the Sun; and his Matter that composes his Body is 1033 times less than the Matter of the Sun. But our Earth, if it be compared with the Sun, is but of a very small Magnitude, and not bigger than a Physical Point; for it is 500000 times less than it. Besides, comparing the Planets with one another, we find that *Jupiter* is bigger than all the rest of the Planets put together; and that he is above 2000 times bigger than the Earth; but *Venus* is of the same bigness with the Earth. And yet there are two of the six Planets, *viz. Mercury* and *Mars* less than the Earth.

LEC-

LECTURE XXVII.

Of the Stations of the Planets.

An inferiour Planet is not ſtationary when it is ſeen in a right Line touching its Orbit.

IF the Earth were at reſt, and the Planets alone turned round the Sun, an inferiour Planet would ſeem to be ſtationary, in that point of its Orbit, where a Line drawn from the Earth touched the Orbit; for when the Planet is near that point, if the Earth ſtood ſtill, it would directly approach the Earth, and would have no viſible Motion, or at leaſt its viſible Motion would be the leaſt of all. In like manner, if a ſuperiour Planet were at reſt, when it is viewed from the Earth, it would appear to ſtand in that part of its Orbit, where a Line drawn from the Planet touches the Earth's Orbit. But becauſe both the Earth and Planets move round the Sun, when an inferiour Planet is in the forementioned Tangent, then the Motion of the Earth will make the Planet appear to change its place, and the Planet will not be come to its apparent Station. And upon the ſame account, when the Earth is in the Line which touches its Orbit and paſſes to a Planet, the proper Motion of the ſuperior Planet will change its viſible place. And therefore it happens, that neither an inferior Planet ſeems to reſt, when it and the Earth are in a Line which touches its Orbit; nor is a ſuperior Planet ſtationary, when the Earth and it are in a Line touching the Orbit of the Earth.

Nor is a ſuperiour ſtationary when it is ſeen in a Line touching the Earth's Orbit.

BUT

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BUT since all the Planets do sometimes appear to move forward, and afterwards to return backwards; between the progressive Motion and the regressive, there will be some point, where it will appear to stand and continue in the same Situation in the Heavens. Now it seems to keep the same Station in the Heavens, when the Line that joins the Earth and Planet's Center is constantly directed to the same point in the Heavens; that is when it keeps parallel to itself: For all Right Lines drawn from whatever point of the Earth's Orbit parallel to one another, do all point to the same Star; because the distance of these Lines is not sensible in comparison of the great distance of the Fixed Stars.

When a Planet appears stationary.

THEREFORE to find out the points of Station, we must inquire the position of the Line, which joyning the Earth and Planet, keeps parallel to itself: For which purpose we must observe, that if the Centers of the Sun, Earth and Planet be joined by Right Lines, they will form a Triangle, whose two sides drawn from the Sun are always equal to the distances of the Earth and Planet from the Sun; and the Base is a Right Line joining the Earth and Planet: And because the sides of this Triangle, in circular concentrick Orbits, do keep always the same Magnitude, the proportion of the Sines of the Angles at the Base will be constantly the same: for the Sines are as the opposite sides.

Table XVI. Fig. 1.

LET the Circle B D G be the Orbit of the Planet, and A H K the Orbit of the Earth concentrical to it. And let us suppose the Earth in A, the Planet in B, and the Sun in the Center S. In the Triangle A S B, the Sines of the Angles A and B at the Base, are as the opposite sides S B, S A.

LET us suppose then that in a small Particle of Time, the Earth is moved thro' the small Arch A C, and the Planet at the same time thro' the Arch of its Orbit B D; their angular Mo-

Motions at the Sun made in the ſame or equal Times, are reciprocally as their Periodical Times; for how much the greater is the Periodical Time, ſo much leſs is the Angle it deſcribes round the Sun in any given Time. Therefore the Angle A S C the angular Motion of the Earth, is to the Angle B S D the angular Motion of the Planet, as the Periodical Time of the Planet is to the Periodical Time of the Earth; that is the angular Motions in the ſame time are in a conſtant Proportion.

Lecture XXVII.

LET the Center of the Earth in C and of the Planet in D be joined by the Line C D, which is parallel to the former Line A B: And in that Caſe, as we have ſhewed, the Planet will appear ſtationary. Let S A cut C D in M, and S D produced cut A B in E: And becauſe A B and C D are parallel, by the 29*th* of *El.* I, the Angle S M D will be equal to the Angle A; but by the 32*d* of the firſt *El.* the Angle S M D is equal to the Angles C and M S C; wherefore the Angle C is equal to the Angle A, bating the Angle M S C or C S A. Likewiſe becauſe of the Parallels A B and C D, the Angle S D C is equal to the Angle S E A, which is equal to the Angles S B A and B S E; wherefore that Angle is equal to the Sum of the two Angles S B A and B S E. Therefore the momentanous Increaſe of the Angle S B A is equal to the angular Motion of the Planet at the Sun. And before it was ſhewed that the Decrement of the Angle A was equal to the Angle A S C, or to the angular Motion of the Earth; but theſe angular Motions are conſtantly in a given Proportion, which is reciprocal to their Periodical Times.

A Planet therefore appears ſtationary when the momentanous Change of the Angle at the Earth, is to the momentanous Change of the Angle at the Planet, as the Periodical Time of the Planet is to the Periodical Time of the Earth.

LET there be two Arches or Angles whoſe Sines are to one another in a conſtant Proportion.

Table XVI. Fig. 2.

Lecture XXVII. tion. I ſay that their Coſines or the Sines of the Complements of theſe Arches, are in a proportion compounded of the direct Proportion of the Sines of theſe Arches, and a reciprocal proportion of the momentanous Changes of the Arches or Angles. For Example, Suppoſe the two Arches A M and C M, whoſe Sines are A B and C D, and their Coſines S B, S D. Let the Arches A M and C M decreaſe into E M and G M; ſo that the Sines E K, G L may be proportional to the former A B and C D. Let A E and C G be the Decrements of the Arches, which being infinitely ſmall may be taken for Right Lines. Draw F E and G H parallel to S M; the Triangles A F E and A S B are equiangular: For the Angles B and A F E are both right, and the Angle E A F is equal to the Angle A S B, the Angle S A B being the Complement of both to a Right-Angle. After the ſame way it may be proved that the Triangles C H G and C S D are equiangular. Therefore C G : C H :: C S : S D; And A F : A E :: S B : A S or C S: Wherefore multiplying the Antecedents together and the Conſequents together, we have the Proportion C G × A F : C H × A E :: C S × S B : S D × A S or C S × S D :: that is S B is to S D in a proportion compounded of A F to C H, and of C G to A E. But the *Ratio* of A F to C H is the ſame with the *Ratio* of the Sines A B and C D; and the *Ratio* of C G to A E is the *Ratio* of the momentary Decrements of the Arches C M and A M. Therefore S B the Co-ſine of the Arch A M, is to S D the Coſine of the Arch C M, in a proportion compounded of the direct proportion of the Sines of theſe Arches, and a reciprocal proportion of the inſtantaneous Decrements of the Arches, that is of C G to A E.

HENCE if the Centers of the Sun, of the Earth, and of a Planet that is ſtationary be joined with Lines, the Coſine of the Angle at the Earth will be to the Coſine of the Angle at the Planet, in a proportion compoſed of the Sines of the

the Angles A and B, and a reciprocal proportion of the momentary Decreaſe of thoſe Angles A and B. But the proportion of the Sines is the ſame with the proportion of the diſtances of the Earth and Planet from the Sun; and the *Ratio* of the momentary Decreaſe of the Angles A and B, is the proportion of the Periodical Times of the Planet and the Earth, as has been proved. Let the Periodical Times be called *t* and T; and then the Coſine of the Angle A will be to the Coſine of the Angle B, when the Planet is ſtationary, as T × S B is to *t* × S A; that is, the Coſine of the Angle at the Earth is to the Coſine of the Angle at the Planet in a proportion compounded of the Periodical Times directly, and a reciprocal proportion of the diſtances from the Sun. Hence the points of Stations are eaſily determined by the following Conſtruction.

LET A H be a portion of the Orbit of the Earth, G B K a portion of the Planet's Orbit, and let the Sun S be in the Center of both Orbits. Cut S A in E, ſo that S A may be to S E as the Periodical Time of the Earth is to the Periodical Time of the Planet. Upon the Diameter A E deſcribe a Semicircle cutting the Orb of the Planet in B, the Angle S A B will be the Elongation of the Planet from the Sun, when it appears ſtationary. Draw the Lines A B F, E B, and S F parallel to E B, and the Angle A B E, in a Semicircle, is a Right-Angle: And therefore A S F parallel to it muſt be right likewiſe. Moreover A S : A F : : Rad. Coſine of A; and alſo B F : S B : : Coſine S B F : Rad. Therefore multiplying the Antecedents together and the Conſequents together, we ſhall have A S × B F : A F × S B : : as the Coſine of S B F is to the Coſine of the Angle A. Therefore the *Ratio* of the Coſine of the Angle A to the Coſine of the Angle S B F, is compounded of the *Ratio* of A F to B F and of S B to A S. But the *Ratio* of A F to B F is equal to the *Ratio* of A S to S E,

Table XVI. Fig. 3.

Lecture XXVII. or of T to *t*. Therefore the *Ratio* of the Cosine of the Angle A to the Cosine of the Angle S B F, is compounded of the *Ratio* of T to *t*, and of S B to S A. But it was shewed that when the Cosines of the Angles had this proportion, then the Planet would be stationary. Therefore it is evident, that when the Planet is in B and the Earth at A, the Planet will appear to be stationary.

HENCE we see that when an inferior Planet is seen from the Earth to be stationary, the Earth also viewed from the inferior will likewise appear to be stationary, and will seem to remain in the same place. For the Earth is seen stationary, when the Line that joins the Centers of the Planet and Earth keeps parallel to itself; and so long as this Line keeps a Parallelism, it will always be directed to the same point in the Heavens.

BY the same Method we find the Positions of the other superior Planets in respect of the Earth and Sun, when they are to be observed by us to be stationary, *viz*. by inquiring where the Earth, considered as an inferior Planet, will appear stationary, seen from a superior Planet.

IF the Periodical Times were proportional to the distances from the Sun, the Points E and B would coincide with G, and the Planet would be stationary when the Angle A was nothing; that is when the inferior Planet was in Conjunction with the Sun: But if S E bore a greater proportion to S A than S G did to S A, the Circle A B E could cut the Planet's Orb in no point at all; and the Planet could no where be stationary, but would appear constantly to move directly forward: But neither of these Cases obtain place in the Planets; for S E is always less than S G or S B, which I thus demonstrate.

CALL the distance of the Earth from the Sun *p*, the distance of the Planet S G or S B call *q*, the Periodical Times T and *t*. And by the universal Law above explained and obser-

ved

ved in all the Planets, we have $T^2 : t^2 :: p^3 : q^3$, and $T : t :: p^{\frac{3}{2}} : q^{\frac{3}{2}} :: p \times p^{\frac{1}{2}} : q \times q^{\frac{1}{2}}$; but as T is to t, so is S A : S E :: p : S E. Say therefore as $p \times p^{\frac{1}{2}} : q \times q^{\frac{1}{2}} :: p$ to $\frac{q \times q^{\frac{1}{2}}}{p^{\frac{1}{2}}}$; which which is therefore equal to S E: And because p is greater than q; therefore $q \times p^{\frac{1}{2}}$ is greater than $q \times q^{\frac{1}{2}}$; and dividing all by $p^{\frac{1}{2}}$, we have q greater than $\frac{q \times q^{\frac{1}{2}}}{p^{\frac{1}{2}}}$ or than S E. And therefore since S B or S G is greater than S E, the Circle upon the Diameter A E will cut the Orbit of the Planet: And therefore we on the Earth, in some certain Positions, may see each of the Planets stationary.

IF you desire to use a Calulation, the Angle at the Earth or the Elongation of the Planet from the Sun is defined in this manner. Let the Radius be z, and the Sine of the Angle at the Earth $q x$; the Sine of the Angle at the Planet will be $p x$, supposing that p is to q in the proportion of the Earth and Planet's distances from the Sun: And because the Sine of the Angle at the Earth is $q x$, its Cosine is $\sqrt{z^2 - q^2 x^2}$; and the Cosine of the Angle at the Planet will be $\sqrt{z^2 - p^2 x^2}$: And therefore $\sqrt{z^2 - q^2 x^2} : \sqrt{z^2 - p^2 x^2} :: T \times q : t \times p$: And squaring the Terms of the Analogy $z^2 - q^2 x^2 : z^2 - p^2 x^2 :: T^2 \times q^2 : t^2 \times p^2$; but $T^2 : t^2 :: p^3 : q^3$: Wherefore instead of T^2 and t^2 put p^3 and q^3, which are proportional to them, and we shall have $z^2 - q^2 x^2 : z^2 - p^2 x^2 :: p^3 \times q^2 : q^3 \times p^2 :: p : q$: And therefore we have the Equation $q z^2 - q^3 x^2 = p z^2 - p^3 x^2$, and $p^3 x^2 - q^3 x^2 = z^2 \times \overline{p - q}$; and $x = z \times \frac{\sqrt{p - q}}{\sqrt{p^3 - q^3}}$

and

Lecture XXVII. and qx the Sine of the Angle at the Earth $= qz \times \frac{\sqrt{p-q}}{\sqrt{p^3-q^3}}$, which is equal to $\frac{qz}{\sqrt{p^2+pq+q^2}}$; therefore the square of the Cosine of this Angle is $z^2 - \frac{q^2 z^2}{p^2+pq+q^2} = \frac{z^2 p^2 + z^2 pq}{p^2+pq+q^2}$; and therefore the Cosine is $z \times \frac{\sqrt{p^2+pq}}{\sqrt{p^2+pq+q^2}}$: The Cosine is therefore to the Sine as $z \times \frac{\sqrt{p^2+pq}}{\sqrt{p^2+pq+q^2}}$ to $\frac{qz}{\sqrt{p^2+pq+q^2}}$ as $\sqrt{p^2+pq}$ is to q. But as the Cosine is to the Sine, so is the Radius to the Tangent; therefore say as $\sqrt{p^2+pq}$ is to q, so z is to $\frac{zq}{\sqrt{p^2+pq}}$, which is the Tangent of the Angle at the Earth: And by this Analogy the Angle is easily found. For if half the Sum of the Logarithms of p and $p+q$ be substracted from the Logarithm of q, there will remain the Logarithmick Tangent of the Angle at the Earth. From this value of the Tangent we have the following Geometrical Construction, which determines the Angle. Let H A Q be a portion of the Earth's Orbit, G B D the Orbit of the inferior Planet, and the Sun in S the common Center of the Orbits. Produce A S till it meets with the inferior Orbit in D; upon the Diameter A D describe the Semicircle A C D, and at S erect upon A D the Perpendicular S C cutting the Semicircle in C; join A C, in which take A F = S D; and from F upon A S let fall the Perpendicular F E; in S C take S L = A E, and draw A L: Then S A L will be the Angle required; and B, where A L cuts the inferior Orbit, will

Table XVI. Fig. 4.

will be the point of the Station: For the square of SC is equal to the Rectangle ASD $= pq$, and AC square $=$ AS square $+$ SC square $= p^2 + pq$: But AC : AF :: AS : AE :: AS : SL :: The Radius : Tangent of the Angle SAL, that is $\sqrt{p^2 + pq} : q :: z : \frac{zq}{\sqrt{p^2 + pq}}$, which is therefore the Tangent of the Angle required.

THESE Calculations and Constructions would sufficiently determine the points of Station, if the Planets Orbits were concentrical Circles: But since they are Eccentrick and Ellipses, both the Angles at the Sun and Planet will be different and changeable, according to the different places of the Planets in their Orbits, at the points of Station. And therefore because in this Case, according to the infinite Varieties of position of the Earth and Planets in their Orbits, there will be likewise an infinite variety of Angles, they cannot be defined by any Algebraical Equation; neither can the *Problem* be universally constructed by any Algebraick Curve of any kind, altho' some Mathematicians have undertaken to do it. Yet if we have the position of a Planet in its proper Orbit, we may find the position of the Earth in its Orbit, from whence the Planet in that point will appear stationary.

FOR this is a determined *Problem*, and admits of two Answers, for the two Roots of the Equation that involves the nature of the *Problem*. The most industrious Dr. *Halley*, hath communicated to me the following Solution of this *Problem*; for the understanding of which we give the following *Lemma*.

WHATEVER the form of the Earth and Planet's Orbits may be, if from their places in the times of Station there be drawn Tangents to the Orbits, and produced 'till they meet; the portions of those Tangents intercepted by their mutual concourse, are proportional to the absolute Velocities of the Earth and Planets.

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Table XVI. Fig. 5.

LET FG and AH be two portions of the Orbits which the Earth and Planet describe; AB and CD two infinitely small portions of them, described in the same time, when the Planet is stationary: Draw the Lines CE and AE touching the Orbits and meeting in E. And because the Planet is stationary, BD and AC will be parallel: And therefore by the *2d Prop. El.* VI. CD:AB::CE:AE. But CD and AB, since they are Portions of the Orbits described in the same time, are as the Velocities of the Earth and Planet: Therefore the Tangents CE and AE, are as the Velocities. This *Theorem* is Mr. *John Bernoulli*'s, and is Published in the *Berline* Acts, and flows immediately from the Parallelism of the Lines AC, BD: But Mr. *Bernoulli* has not given us from thence any Solution of the Problem. Dr. *Halley*'s Solution is this.

PROBLEM.

To find the Place of the Earth, from which a Planet seen in a given Point of its Orbit would appear Stationary.

SUPPOSE the Sun at S, ΠKLA the Orbit of the Earth, which we may here suppose to be Circular, $\pi P \alpha$ the Orbit of the Planet, P its given place. Draw VPQ touching the Orbit in P, and intersecting the Orbit of the Earth in V and Q, Bisect VQ in R, and on it erect the Perpendicular PB, which may be to VR or RQ, as the Velocity of the Planet is to the Velocity of the Earth: At the Center R, upon the Diameter VQ, describe the Semicircle V*bd*Q, to which draw the Tangents B*b*, B*d*, and produce them till they meet with VQ produced in Σ and T; draw R*b*, R*d*; take ΣK equal *b*Σ, and TL equal to *d*T. Then I say, the Points K and L, are what

what were to be found. For because of the Equiangular Triangles $Rb\Sigma$ and $BP\Sigma$, $\Sigma P : PB :: \Sigma K : Rb$ or RV, and by alternation of Proportion, $\Sigma P : \Sigma K :: PB : RV$; but by Construction, PB is to RV as the Velocity of the Planet is to the Velocity of the Earth; and Σb touches the Semicircle in b; wherefore its Square is equal to the Rectangle $V\Sigma Q$, by *Prop.* 36 *Elem.* III. And ΣK is equal Σb; therefore ΣK will touch the Orbit of the Earth in the Point K, by 37 *Prop. Elem.* III; therefore the Tangents of both Orbits ΣP and ΣK, are as the Velocities; and therefore a Planet in P, will appear Stationary, when the Earth is in K. In the same manner it may be shewed, that the Right-Lines PT and LT, are as the Velocities, and that LT touches the Orbit of the Earth in L. Lastly, the Lines SK SL being drawn, will shew the Places of the Earth seen from the Sun, and the Angles KSP LSP are the Commutations. And if the Line SA be the Line of the *Apsides* of the Earth's Orbit, KSA and LSA, will be the Angles of the true Anomaly; and consequently if any error be committed in supposing the Earth's Velocity, it can be most accurately corrected, by having the true Anomaly.

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IT is a *Problem* of a very different kind, to define the Time when a Planet is to be Stationary, and its Solution cannot be had from common *Geometry*; yet the aforesaid Dr. *Halley*, by an indirect Method, and an Approximation, has shewed how to find it. It is as follows.

WHEN the Time of a Station is to be accurately determined.

HAVING by the former Construction, or a rude Calculation, or even from an *Ephemeris*, found out the Day of the Station, find out by the most perfect *Astronomical* Tables, for the Meridian of that Day, the Place of the Sun; as

Lecture XXVII. also the Planets *Heliocentrick* and *Geocentrick* Places, and the *Logarithms* of their diſtances from the Sun; and for to reduce their Motions to the ſame Plane, *Curtate* the diſtance of the Planet, and we have the Triangle STP, from the Principles of *Aſtronomy*, where S in repreſents the Sun, T the Earth, and P the Planet. Draw TQ a Tangent to the Earth's Orbit, and PQ a Tangent to the Planet's Orbit, which meet in Q. Now if the real Velocities of the Planet and Earth are as PQ and TQ, or as the Sines of the Angles PTQ and TPQ, it is plain that the Planet is then in the Situation required; that is, it will be there Stationary.

HAVING now the diſtances ST, SP, we have the *Ratio* of their real Velocities, or of Tt and Pp. For the real mean Velocities of different Planets, that is, thoſe Velocities with which at diſtances equal to half the Tranſverſe Axes of the Orbits, they would deſcribe Circles, are in a reciprocal ſubduplicate Proportion of the Axes. And * the mean Velocity of any Planet, is to its Velocity in any other Point P or T, in a ſubduplicate proportion of its diſtance from the Sun, to its diſtance from the other *Focus* of the Ellipſe, which call reſpectively PF and TF: and putting R for half the Tranſverſe Axe of the Superiour Ellipſe, and r for half the tranſverſe Axe of the Inferiour, and then compounding the *Ratios*, the Velocity of the Inferiour Planet, will be to that of the Superiour, or Tt to Pp as $\sqrt{R \times SP \times TF}$ is to $\sqrt{r \times ST \times PF}$; and therefore we muſt have ready the Logarithm of this Ratio reduced to the Plane of the Ecliptick.

* See the Theor. Lect. XVIII.

FROM the ſame diſtances, we have likewiſe the Angles STQ and SPQ; for the Radius is to the Sine of the Angle STQ, as $\sqrt{ST \times TF}$ is to half the Conjugate Axis of the Orbit; and likewiſe the Radius is to the Sine of SPQ, as $\sqrt{SP \times PF}$ to half the Conjugate Axis of the Planet's

Planet's Orbit: or, which is more readily perform'd; say, as the distance of the Planet in its *Aphelion* is to its distance in the *Perihelion*, so the Tangent of half the Angle, by which it is distant from the *Perihelion*, to the Tangent of an Angle, which being substracted from the foresaid half, leaves the Complement of the Angle SPQ to a Right, or its excess above a Right, as it happens that this Angle is acute or obtuse. Reduce this Angle if it is needful to the Plane of the Ecliptick, and these things being done, substract the Angle STQ from the Angle STP, and to the Angle SPQ add the Angle SPT, and we shall have the Angles QTP and QPT; and if the Sines of these Angles have the same Proportion that the real Velocities have in the Points T and P, the estimation is right: But if not, take the difference of the Logarithms of each, or the error of the first Position. And if the Ratio of the Velocities be less than the Ratio of the Sines, we must diminish the Angle TSP, by adding or substracting a known Mean Angle, such as will agree to one Days Motion; and the contrary is to be done, if the Ratio of the Velocities be greater. And by a Calculation just like the former, seek the Logarithms of the aforesaid Ratios, for the Noon of the preceding or following Day, as the case requires. Then compare the differences of the foresaid Logarithms, or the error of the first Position with the error of the second; and the Sum of the errors, if they be of several kinds, or their difference if they be of the same sort, will be to 24 Hours, as either of the errors to the time between the Point of Station and the Noon on which the assumed error was found. This is plain to those who understand the Rule of False.

IN this manner the Stations of the Planets may be obtained within a few Minutes. But for to take away the small errors which may arise, by reason the Logarithms do not uniformly encrease as the Time, if any one pleases, he may

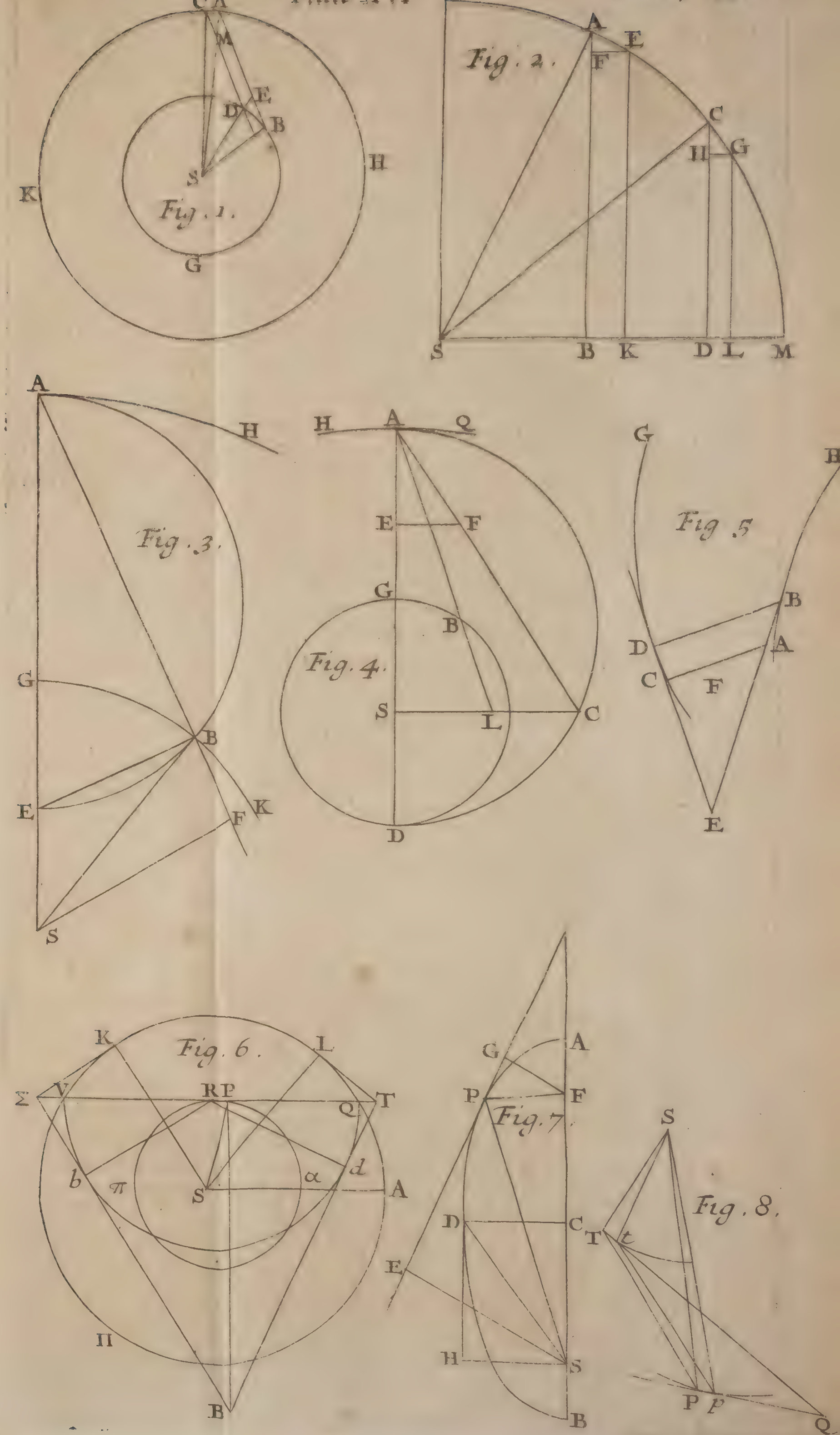
Lecture XXVII. renew the Calculation, for the Time juſt found out, and which is very near the Truth, and ſo bring out the true Time to a Minute; but there is no need of this Correction but in *Mercury* or *Mars*.

FOR to make this plainer we will add an Example of the Station of *Jupiter*, which lately happened on *November* the 9*th* 1717.

	November 9*th* at Noon.				*Nov.* 10*th* at N.			
	S	gr.	′	″	S.	gr.	′	″
The Mean Anom. of ♃	9	10	00	00	9	10	5	00
Mean Motion of ☉	7	00	7	00	7	1	6	8
♃ Helio. from the 1 of ♈	2	25	11	00	2	25	15	53
☉ Place from the 1 of ♈	6	28	53	17	6	29	54	00
Log. diſt. of ♃ from the Sun	5,720650				5,720680			
Log. diſt of ☉ from the Sun	4,994267				4,994186			
♃ Geocentrick place	3	5	4	28	3	5	4	27
The Angle STP		113	48	49		114	49	33
The Angle SPT		9	53	28		9	48	34
The Angle STQ		89	23	54		89	23	54
The Angle SPQ		92	41	20		92	41	14
The Angle PTQ		24	25	42		25	25	39
The Angle TPQ		102	34	48		102	29	48
Log. of the Ratio of Velocit.	0,368210				0,368321			
Log. of the Ratio of the Sines	0,372912				0,356757			
The Error of the 1ſt Poſition	0,004702				0,011564			
The Error of the 2*d* Poſition	0,011564							

AND becauſe one of theſe Errors does exceed the Truth, and the other is deficient from it, ſay, as 16266 the Sum of the Errors, is to 4702, ſo is 24 Hours to 6 Hours 56 Minutes. Hence we conclude the Time of the Station of *Jupiter* to have been, *November* the 9*th*, Six Hours and 56 Minutes after Noon.

Plate XVI



LECTURE XXVIII.

Of the Division of TIME, *and its Parts.*

THE Parts of *Time* are known to all Men, being Days, Hours, Weeks, Months and Years. A Natural Day is determined by the Apparent Motion of the Sun from East to West, and is that Space of *Time* that flows while the Sun goes from any Meridian, or Horary Circle, 'till it arrives to the same again. It is called Natural to distinguish it from that signification of the word Day, which is opposed to Night, and which is called the Artificial Day.

A Natural Day.

ALL Nations do not begin their Day alike. The *Babylonians* counted the Beginning of their Day, from the Sun rising. The *Jews* formerly and the *Athenians*, from Sun setting; which the *Italians*, *Austrians* and *Bohemians* do at this time; so that when the Sun comes to the Western Horizon, they count the Twenty-fourth Hour; and the Hour after the Sun is sett, they call the first Hour.

The different Beginnings of the Day.

THEY who begin their Day at Sun rising, have this advantage, that their Hours tell them how much Time is already gone since Sun rising; and they who reckon their Hours from Sun setting, have this use of it, that they know how long it is to Sun setting, that they may proportion their Journeys and Labours for that Time. But both of them have this Inconvenience, that they cannot immediately tell by their Hours the Times of Midday or Midnight, but they must

Lecture XXVIII compute by the length of the Day time, or the Seafon of the Year; for in different Seafons, the Time of Midday is reckoned by different Hours. The *Egyptians* antiently began their Day at Midnight, from whom *Hipparchus* that Antient and Famous *Aſtronomer*, brought that way of reckoning into *Aſtronomy*. And *Copernicus* and fome other *Aſtronomers* have followed him therein. But the much greater part of the *Aſtronomers* have thought it better to begin their Day from Noon. Yet the Method of beginning from Midnight is received in *Britain*, *France*, *Spain*, and moft of the Nations in *Europe*.

THERE are two forts of Hours, equal and unequal. An equal Hour is the Twenty fourth part of the Natural Day. Befides the divifion of Hours received by the Vulgar into half Hours, Quarters, and half Quarters, we now generally follow the *Aſtronomical* Divifion, and reckon every Hour 60 Minutes, in every Minute 60 Seconds, and in every Second 60 Thirds, &c.

AN unequal Hour is the Twelfth Part of the Artificial Day, or the Twelfth part of the Night; and it is called the *Temporary Hour*, becaufe at different Seafons of the Year, it is of a different Length. For a diurnal Hour in the Summer is longer than one in the Winter; a Night Hour is fhorter. But in the Equinoctial Day, the Hours in the Day and Night are equal to each other; and therefore the equal Hours are called *Equinoctial*. The *Jews* and *Romans* formerly ufed thefe Hours, and the *Turks* reckon by them at this Day, and their Noon always falls upon the Sixth Hour of the Day. Thefe Hours are alfo called *Planetary Hours*, becaufe in every Hour they fuppofed one of the feven Planets to prefide over the World, and they took it by turns; fo that the firft Hour after Sun rifing fell on *Sunday* to the Sun; the next to *Venus*; the third to *Mercury*; and the reft in order to the Moon, *Saturn*, *Jupiter* and *Mars*. By this means, on the firft Hour of the next day the Moon prefided, and on that account

account gave the Name to that Day; and the Days of the Week by this Method have had their Names from the Planet that governed the first Hour, 'till the end of the Week. Lecture XXVIII

A Week. A Week is a Syſtem of ſeven Days, in which each Day is diſtinguiſhed by a different Name. The Chriſtian Church called the firſt Day of the Week the *Lord's-day*, the Vulgar term it *Sunday*, and none but the *Phanaticks* of our Time, ever called it *Sabbath-day*. The reſt of the days of the Week were called *Feriæ*, *Munday* the ſecond *Feria*, *Tueſday* the third *Feria*, *&c.* and *Saturday* they alſo called the *Sabbath-day*. But the common People uſe the ſame Names that were given by the *Romans*; each Day being denominated from a Planet.

A Month. A Month is properly that Space of Time the Moon takes to perform its Courſe in the *Zodiack*; which, in the Space of a Year, it runs over Twelve times. There is another Month nearly equal to it, which is meaſured by the Motion of the Sun, and is that ſpace of Time, in which the Sun moves through one Sign, or Twelfth part of the Ecliptick: Theſe Months are properly *Aſtronomical*. A Civil Month is different from them, and conſiſts of a certain number of Days, fewer or more, according to the Laws and Ordinances of the Kingdom or Republick in which they are obſerved. The *Egyptians* made each Month to conſiſt of 30 Days, and the Year conſiſting of 5 Days more than 12 Months, they added them to the end of the Year, and called them *Epagomenæ*.

The Civil Year of two ſorts. THE Year is either *Aſtronomical* or Civil; both kinds of the *Aſtronomical* Years, *viz.* the *Tropical* and *Periodical*, we have already defined in our XXII *Lecture*. The Civil Year is the ſame with the Political Year eſtabliſhed by the Laws of a Country, and is of two kinds, Lunar or Solar, according as it is deſigned to be regulated by the Motions of the Moon or Sun. There are two ſorts of Lunar Years, the one moveable

Lecture XXVIII

The moveable Lunar Year.

moveable, the other Fixed: The moveable Year consists of Twelve Synodick Months, or of Twelve Lunations which are compleated in 354 Days, and after that time the Year begins again. This Year is less than the Solar Year, which brings back all the Seasons by Eleven Days. And therefore the beginnings of such Years move thro' all the Seasons, and that in the space of 32 Years: This Form of a Year is observed by the *Turks* and *Mahometans.*

The Fixed Lunar Year.

SINCE Twelve Lunations is less than a Solar Year by Eleven Days, three Lunar Years are less than three Solar Years, by 33 Days; and therefore to keep the Months in the same Seasons and times of the Solar Year, to the third Year there is a whole Month added, and it consists of 13 Months: And this is done as often as is needful, to keep the beginning of the Year always in the same Season. And the Month added is called an *Embolimæan* or Intercalary Month. In nineteen Years there are seven such Months, and this kind of Lunar Years are called Fixed, and were observed by the *Greeks*, whom the *Romans* followed in this matter 'till the times of *Julius Cæsar.*

The Solar Year.

THE Solar Year, which is made conformable to the Motion of the Sun, is likewise of two kinds, moveable and immoveable. The moveable is called the *Egyptian* Year, because observed in that Country: and it consists of 365 Days, and is less than the Tropical Year in which the Sun runs his Course in the Ecliptick, by almost six Hours. By the neglecting of these six Hours, it happens that four such Years is less than four Tropical Solar Years by a whole Day: And therefore in four times 365 Years, that is, in 1460 Years, the beginning of the Years moves thro' all the Seasons of the Year.

SINCE therefore an *Egyptian* Year is less than a true Solar Year, by almost six Hours; that all the Years may go on according to the Sun's Motion, a regard must be had to these six Hours. But it is requisite also, that the Political Year have

have always the ſame beginning, and that it commence with the Day; for it would be inconvenient to have the Year begin ſometimes at one Hour of the Day, ſometimes at another; which would neceſſarily fall out if we added to every Year ſix Hours. Now theſe Hours amounting in three Years to Eighteen Hours, if they be added to the ſix Hours of the fourth Year, will make a whole Day: Therefore this Day being added to the fourth Year, will reduce it again to be even with the Motion of the Sun. *Julius Cæſar* perceiving this, ordered that every fourth Year ſhould have an Intercalary Day, which therefore conſiſts of 366 Days; and the Day added is put in the Month of *February*. And becauſe in the common Year the 24*th* of *February*, in the *Roman* way of reckoning, was the ſixth of the *Kalends* of *March*, or the ſixth Day before the *Kalends* of *March*, *Cæſar* ordered that for that Year there ſhould be two ſixths, or that the ſixth of the Kalends of *March*, ſhould be twice reckoned; upon which account the Year was called *Biſſextile*, which we name the Leap-Year. This Form of a Year was inſtituted by *Julius Cæſar*, who was then High-Prieſt among the *Romans*, and was called the *Julian* Year; whoſe nature is, that every fourth Year conſiſts of 366 Days, and the other three only of 365.

BUT it muſt be acknowledged, that the time appointed by *Julius Cæſar* for the Solar Year, is too much; for the Sun finiſhes his Courſe in the Ecliptick in 365 Days, 5 Hours and 49 Min. and therefore he begins again his round, Eleven Minutes before the Civil Year is ended. So that if the Sun in any Year has entered the Equinox upon the 20*th* of *March* at Noon-day, after 4 Years he will arrive at the Equinox 44 Minutes before Noon, and the fourth Year after that he will be there 1 h. 28 Min. before Noon; and ſo every Year 11 Minutes ſooner than by this reckoning; ſo that in 131 Years, he will anticipate or enter the Equinox a whole Day before the 20*th* of

March;

Lecture XXVIII *March*: And therefore the Cæleſtial Equinox will not always fall upon the ſame Day of the Month, but by degrees it will move towards the beginning of the Year: and this ſo ſenſibly in compaſs of time, that it cannot be doubted.

HENCE in the time of the Council of *Nice* (about which time, the Terms were ſetled for obſerving *Eaſter*) the Vernal Equinox fell upon the Twenty firſt of *March*: but the Equinox continually falling backwards in the Year, in the Year of *Chriſt* 1582, when the *Kalendar* was corrected, it was found that the Sun entered the Equinoctial Circle on the 11*th* of *March*, and was departed Ten whole Days from its former place in the Year: And therefore when *Gregory* the XIII of that Name, Biſhop of *Rome*, deſigned to place the Equinocties in their former Situation in reſpect of the Year; he took thoſe Ten Days out of the *Kalendar* that Year, and ordered that the Eleventh of *March* ſhould be reckoned as the Twenty firſt: And to prevent the Seaſons of the Year from going backwards as they did before; he ordained, that every Hundredth Year, which in the *Julian* Form was to be a *Biſſextile*, ſhould be a common Year, and conſiſt only of 365 Days; but becauſe that was too much, every fourth Hundred was to remain *Biſſextile*. This new Form of the Year being eſtabliſhed, by the Authority of the Biſhop of *Rome Gregory* XIII, is called by his Name the *Gregorian* Year, and is received in *France*, *Spain*, *Italy*, *Germany*, and in all the Countries where the *Pope*'s Authority is acknowledged; as likewiſe lately in ſeveral where the Reformed Religion is obſerved. Yet in *Britain* and other Northern Countries, the *Julian* Form of the Year is ſtill retained.

The Gregorian *Year.*

THE *Perſians* obſerve the *Egyptian* Form of the Years to this Day, whence it is that the Equinocties remain not in the ſame Month, but move thro' them all, and after a Period of about 1460 Years, the beginning of their Years falls in with the ſame time of the true Solar Year. This Time or Period

riod is called the *Great Canicular Year*, or the *Sothiacal* Period, because it takes its beginning on the first Day of the Month *Thoth*, or the first Day of that Year, when the Dog Star rises Heliacaly, for the Word *Sothis* in the *Egyptian* Language signifies the Dog, which in *Greek* is called ἀςροκύων, that is the Dog-star, which the *Astronomers* Name *Sirius*. Lecture XXVIII

THE Antients not only distinguished the Times by Years, but by several Revolutions or Collections of Years; such was the *Jubilee* of 49 or 50 Years; an Age consisted of a Hundred Years. But among the *Greeks* the *Olympiads* were esteemed the most Famous, each of them containing the space of four Years.

AS in the Heavens there are certain Points from which the *Astronomers* begin their Computations of the Planets Motions, so also there must be certain Points or Instants of Time, from which as from Roots, all Calculations must begin: and all Memorable Actions are disposed and recorded, according to the Series of Years which follow from that Root. These Roots are called *Epoch's* or *ERA*'s, from which we generally count our Years and Times. The most famous, best known, and most used by us, is that which is reckoned from the Nativity of our Lord *Jesus*, which begins at the *Kalends* of *January* that immediately followed his Birth.

NOW altho' this *Epoch* is generally received by Christians, yet the *English* and *Irish* have an *Epoch* a whole Year posterior to it, which they commonly use in all Publick and Ecclesiastical Affairs: for they do not begin their Year with the first of *January* that follows the Nativity, but with the Feast of the Conception or Incarnation, which is observed on the 25*th* of *March*; and therefore it is that the *English* reckon from the Feast of *Lady-day* 1718, that there are compleated 1717 Years; but from the Birth of our Lord to the Feast of the Nativity of the Year 1717, they

number

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number only 1716 Years elapſed, whereas all the reſt of the Chriſtian World count 1717 Years.

The Author of the Æra.

IN this Affair they exactly agree with *Dionyſius* ſurnamed the leſs, according to whom *Chriſt* is ſuppoſed to have been conceived the 8*th* of the Kalends of *April*, in the firſt Year of this *ÆRA*; and was born the Winter following, at the end of the 46*th* Year from the Reformation of the Kalendar by *Julius Cæſar*. This way of computing was at firſt univerſally received, but afterwards by degrees and tacitely, all Nations receded from it; ſo that it does only now take place in *England*, and the Dominions thereof; and the common Opinion is that *Chriſt* was Born the Winter preceding the Time that *Dionyſius* reckoned the conception to have been; and by this means they make *Chriſt* to have been a Year before *Dionyſius* the Author of the *Æra* ſuppoſed he was Born.

BUT yet for all this the *Engliſh* for the greateſt part of the Year, deſign it by the ſame number that the reſt of the Chriſtian World does: but for three Months, *viz.* from the Kalends of *January* to the 8*th* of the Kalends of *April*, they write one Year leſs.

THERE is likewiſe the *Epocha* of the *Creation*, which is much noted, yet about it there are great Controverſies among the *Chronologiſts*; ſome affirming that the World was created 3950 Years before the Birth of *Chriſt*; others again ſay, that at the Birth of *Chriſt* the Age of the World was 3983 Years. The *Greek* Church and the Emperors of the Eaſt uſed an *Epocha* of the Creation, which was much more antient, and makes the World to have been Created 5509 Years before the coming of *Chriſt*.

AMONG the Prophane Authors, the Antienteſt *Epocha* is that of the *Olympiads*, which begun at the Summer of the Year 777 preceding the Birth of *Chriſt*, and on the Kalends of *July*.

THE *Epoch* of *Rome*, or of the Building of the City, is not long after the *Olympiads*, and there are

are two of them, the *Varronian* and *Capitolian*; according to the first, the City was built the Year before *Christ* 753; according to the other it was in the Year 752. Lecture XXVIII

THE *Æra* of *Nabonassar* has always been famous among the *Astronomers*, and began on the *6th* of *February* of the *Julian* Year carried backward, and before *Christ* 747. And because that Day was then the first Day of the *Egyptian* Year, *Ptolemy*, and after him *Copernicus*, computed the Motion of the Stars according to that *Æra* by *Egyptian* Years; for the *Egyptian* Year is very convenient for *Astronomical* Calculations, it being interrupted by no intercalary Days.

AFTER this we have another *Epocha* of the Death of *Alexander* the Great, the three Hundreth and Twenty fourth Year before *Christ*, on the 12*th* of *November*; which was then the first Day of the *Egyptian* Year. *Theon*, *Albategnius*, and some others, have computed from thence according to the *Egyptian* Year. Between the two *Æras* of *Nabonassar* and of the Death of *Alexander*, there are precisely 424 *Egyptian* Years. The *Abissines* reckon by another *Æra*, which is called the Æra *of the Martyrs or of* Dioclesian. The *Turks* and *Arabians* reckon by an *Æra*, which they call the *Hegira*, which takes its beginning from the flight of *Mahomet*. The *Persians* have likewise an *Epoch* which they call *Iesdegird*; all which are are explained by the *Chronologists*. But the *Julian* Period seems to be the most useful and convenient of all, it including almost all other *Æras* within it, and it is a Period of 7980 Years; which Number is composed by the Multiplication of the three numbers, 15, 19 and 28. The first is the *Cycle* of the *Indiction*; the second is the *Metonick Cycle* of the Moon; and the third is the *Cycle* of the Sun. And the first Year of this Period was that wherein all these three *Cycles* began together. I will here add a Table, which gives the first Year of the several *Æras*, and reduces

duces them to the Years of the *Julian* Period; and to the Years before, or after the Birth of *Christ*.

	Years before Christ	*Years of the* Julian *Period*
The Creation of the World, according to the *Greek* Emperors.	5508	
The Common *Æra* of the Creation.	3950	765
The Beginning of the *Olympiads*.	776	3938
The building of *Rome*, according to *Varro*	753	3961
The Building of *Rome*, according to the Regifters of the Capitol.	752	3962
The *ÆRA* of *Nabonaſſar*.	747	3967
The Death of *Alexander* the Great.	324	4390
	Years after Chrift.	
The common Chriftian *Epoch*.	1	4714
The *Diocleſian Æra*.	284	4997
The *Hegira* of the *Turks*.	622	5335
The *Jeſdegird* of the *Perſians*.	632	5345

LEC.

LECTURE XXIX.

Of the Kalendars. *Of* Cycles *and* Periods.

THE *Kalendar* is a Table, in which are set down all the Days of the Year, in a regular disposition, according to their Months, with a distribution of them into Weeks. The Vigils, Holy-days and Law-days, together with the *University* Terms, are likewise annexed. The distribution of Days into Weeks, is made by the seven first Letters of the Alphabet, ABCDEFG. Beginning at the first of *January*, to it place the Letter A; to the second of *January* B is joined; to the third C; and so on to the seventh, where G is figured: And then again beginning with A, which is placed at the Eighth Day; B will be at the Ninth; C at the Tenth; and so continually repeating the Series of these seven Letters, each Day of the Year has one of those Letters in the *Kalendar*. By this means the last of *December* has the Letter A joined to it. For if the 365 Days which are in a Year be divided by seven, we shall have 52 Weeks, and one Day over. If there had been no Day over, all the Years would constantly begin on the same Day of the Week; and each Day of a Month would constantly have fallen upon the same Day of the Week. But now because besides the 52 Weeks in the Year, there is one Day more, from thence it happens that on whatever Day of the Week the Year begins, it ends upon the same Day; and the next Year begins with the following Day. For

The Kalendar.

The Dominical Letters.

Lecture XXIX. Example, in a common Year of 365 Days, if the Year begin on a *Sunday*, it will end on *Sunday*; and the first Day of the next Year will be *Monday*.

THE Letters being ranked in this order; that Letter which answers to the first *Sunday* of *January* in a common Year, will shew all the *Sundays* thro'out the Year; and to whatever Days in the rest of the Months that Letter is put, these Days are all *Sundays*; and therefore that Letter is called the *Dominical* or *Sunday* Letter of that Year. So also whatever Letter is joined to the first *Monday* in *January*, the same, as often as it is repeated in the *Kalendar*, shews the *Mondays* thro'out the Year.

IF the first Day of *January* be a *Sunday*, the last Day of the Year, as I have said, will likewise be a *Sunday*; and therefore the next Year will begin on *Monday*, and the *Sunday* will fall on the seventh Day, to which is annexed the Letter G; which therefore will be the *Sunday* Letter for all that Year: And since the Year began on *Monday*, it will also end on that Day; and the following Year will begin on a *Tuesday*, and the first *Sunday* will fall upon the sixth of *January*, to which Day is adjoined the Letter F, which is the *Sunday* Letter for that Year. And in the same manner for the Year next following, the *Dominical* Letter will be E: By this means the *Sunday* Letters will go in a retrograde order by G F E D C B A. In the Yearly *Kalendars*, which we call *Almanacks*, which is an *Arabick* Word, the *Dominical* Letter, for to distinguish it the better, is made a Capital, and all the rest are of a smaller Form. By this means, at one view, we shall see all the *Sundays* in the Year.

IF all the Years were *Egyptian* Years of 365 Days, after a Period of seven Years, the same Days of the Month would return to fall on the same Day of the Week. But we observing the *Julian* Year, where every fourth is *Bissextile* or consists of 366 Days, in which besides the 52 Weeks there are two Days over. If that Year should

begin

begin with a *Sunday*, it will end on a *Monday*; and the next Year will begin on *Tuesday*, and the first *Sunday* of that Year will be on the sixth of *January*, to which is annexed the Letter F, which will be the *Dominical* Letter for the Year following that Leap-year whose *Dominical* Letter was A.

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BY this means, the *Bissextile* Year returning every fourth Year, the Series of the *Dominical* Letters succeeding each other is interrupted, and does not return in order 'till after four times seven, or Twenty Eight Years. Hence ariseth the *Cycle* of 28 Years, which is called the *Cycle* of the Sun; which being compleated, the Days of the Months return in the same order to the same Days of the Week. In this *Cycle* all the *Bissextile* Years have two *Dominical* Letters, the first of which takes place till the 24*th* or 25*th* of *February*, and the other serves for all the rest of the Year: For in the *Bissextile* Year the 24*th* and 25*th* of *February* are esteemed as one and the same Day, and both of them have the same Letter F annexed to them; and by this the order of the *Sunday* Letter is interrupted. For Example, if in the beginning of the Year, the *Sunday* Letter is E, the 24*th* of *February* will fall upon a *Monday*, and the 25*th* on a *Tuesday*; both which Days are marked with the Letter F; and therefore the following Letter G, which shewed the *Tuesdays* before, will now point out the *Wednesdays*; and the next *Sunday* will fall upon the sixth of *March*, to which in the *Kalendar* is annexed the Letter D; which will point out the *Sundays* for all the rest of the Year, and then becomes the *Dominical* Letter.

The Cycle *of the Sun*.

THE first Year of the *Cycle* of the Sun is a *Bissextile*, and the *Dominical* Letters answering to it are G and F. For the second Year the *Sunday* Letter is E; for the third D; the fourth C; and again the fifth Year of the *Cycle* being a *Bissextile*, has two *Dominical* Letters B and A; and so in the rest. The following small Table

 shews

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ſhews what *Dominical* Letter belongs to each Year of the *Cycle*.

1	G F	5	B A	9	D C	13	F E	17	A G	21	C B	25	E D
2	E	6	G	10	B	14	D	18	F	22	A	26	C
3	D	7	F	11	A	15	C	19	E	23	G	27	B
4	C	8	E	12	G	16	B	20	D	24	F	28	A

TO find the Year of the Cycle *of the Sun, for any Year of the Christian* Era. To the current Year of *Chriſt* add 9, becauſe from the beginning of the *Cycle*, 'till the firſt Year of *Chriſt*, there were 9 Years paſt: Divide the Sum by 28, the Quotient ſhews the number of *Cycles*, that have revolved ſince the firſt Year before *Chriſt*, 'till the current Year; and the remainder, if there be any, is the current Year of the *Cycle*; but if there be no remainder, than 28 is the current Year of the Solar *Cycle*.

The moveable Feaſts.

BESIDES the fixed and ſettled Feaſt, which are always on certain and determined Days of the Year, there are other Feaſts and Holy-days, which are moveable, and in different Years fall upon different Days of the Month, and ſometimes in different Months: Theſe Holy-days are not regulated by the Motion of the Sun, but by that of the Moon: Such was the Feaſt of the *Paſſover*, inſtituted by God himſelf, for the *Jews* to obſerve; and is ſucceeded by the Chriſtian *Eaſter*, in Memory of our *Saviour*'s Reſurrection. God ordained that the Paſſover ſhould be Celebrated in the firſt Month, the 14*th* Day of the Month at Even. *See* Leviticus *Chap.* XIII. Now the *Jewiſh* Year was a Lunar Year, and ſo ordered by Intercalary Months, that the Month whoſe fourtenth Day, or whoſe full Moon, fell either on the Vernal Equinox, or next after it, was reckoned the firſt Month of the Year. The Chriſtian Church was willing to obſerve the ſame Method in celebrating of *Eaſter*. But yet to diſtinguiſhed it from the *Jewiſh* Paſſover, would not keep the Feaſt on the 14*th* Day, but

The Feaſt of Eaſter.

on

on the *Sunday* after, because our Lord rose upon the *Sunday* after the *Jewish* Passover. Lecture XXIX.

THEREFORE for determining the time for the celebration of *Easter*, we must define the Time of the Equinox, which was believed to be fixed to the Twenty first of *March*, and the Fathers thought it could never happen on any other Day; and therefore they made their *Kalendar* upon that supposition. Then they called that the *Paschal* or first Month, whose 14*th* Day or Full Moon fell on the Equinoctial Day, that is on the 21*st* of *March*, or next followed the 21*st* of *March*. But because the *Jewish* Months were Lunar Months, the 14*th* Day immediately preceded the Full Moon; therefore for the Time of the Observation of *Easter*, we must have a regard to the Motion of the Moon, and the Times of New Moons and Full Moons must be found. The *Jews* had no other way of finding the New Moon, but by Observing it; and when the Moon first appeared to emerge out of the Sun's Rays, or to rise in the Evening Heliacly, that Day they called the first Day of the Moon or Month. The Christian Church computed their Lunations by the *Metonick Cycle* of 19 Years; and therefore they inserted this *Cycle* in their *Kalendars*, and called its numbers the *Primes* or *Goldnumbers*, by which they determined the Times of the Lunations.

The Cycle *of the Moon, or the* Metonick Cycle

THE *Metonick Cycle*, called so from its Inventor *Meton*; is also termed the *Cycle* of the Moon, and is a Period of 19 Years, which when they are compleated, the New Moons and Full Moons return on the same Days of the Month; so that on whatever Days the New and Full Moons fall this Year, 19 Years hence they will happen on the very same Days of the Months, as *Meton* and the Fathers of the Primitive Church thought. And therefore at the Time of the Council of *Nice*, when the way of setling the Time for Observing the Feast of *Easter* was established; the numbers of the Lunar *Cycle* were

 inserted

Lecture XXIX. inserted in the *Kalendar*; which upon the account of their excellent use, were set in Golden Letters, and the Year of the *Cycle* for any Year, was called the Golden Number of that Year.

THE Golden Numbers were placed in the *Kalendar*, according to the following Method; taking any Year for the beginning of the *Cycle*, which they reckoned by the number 1, and observing every Month the Days on which the New Moons happened that Year, just by those Days they joined the Number 1. And because in that Year the New Moons happened on the Twenty third of *January*, the Twenty first of *February*, the Twenty third of *March*; the Twenty first of *April*; the Twenty first of *May*; the Nineteenth of *June*, and so in the rest; just by those Days in the Column of the Golden Number, they put the number 1. The second Year observing the New Moons, to the Days on which they happened they inscribed the Number 2, *viz.* to the Twelfth of *January*; the Tenth of *February*; the Twelfth of *March*; the Tenth of *April*; and so on in the rest of the Months. The same thing was done the Third Year, annexing the Number 3 to all the Days the Moon changed in that Year, and so on in the following Years, 'till the whole Period of 19 Years was compleated. But the most accurate disposition of the Golden Numbers, is by the Mean Lunations, as they are sett down in the *Astronomical* Tables, for every Month and each Year of the Lunar *Cycle*; And fixing according to that Computation the Character of the Year to each Day, on which the Lunation happens.

BECAUSE a Lunar *Astronomical* Month consists of 29 Days, 12 Hours, 44 Minutes and 3 Seconds; the common People, who cannot distinguish the small Particles of Time, do make the Lunar Months to consist of intire Days without Fractions, and on that account they alternately put one Month of 30 Days, and the next of 29 Days, these are called Hollow or Cave,

that

that is, deficient Months, the others Full; the 12 Hours over the 29 Days requiring this alternation: But because there are 44 Minutes besides, which is almost three Quarters of an Hour in every Lunation, in 32 Lunations these Minutes will make up a whole Day, which is to be added to a Hollow Month, and by this means the Lunations of the *Kalendar* will nearly agree with those of the Heavens.

IF we know the Year of the Lunar *Cycle*, which in our *Liturgy* is called the *Prime*, we have the Days of the Moons change thro'out the Year; for in each Month the Golden Number or *Prime* is set to the Day the change happens on; and adding to that 14 Days, we shall have the Day of Full Moon.

THE Antients imagined that the *Cycle* of 19 Years did exactly compleat 235 Lunations; and therefore after the Revolution of that Time, the New Moons not only fell on the same Days of the Month, but likewise on the same Hours of the Day, which is not true: For in 19 *Julian* Years there are 6939 Days and 18 Hours. But if to every Lunation we allow 29 Days, 12 Hours, 44 Minutes, 3 Seconds, which the Motion of the Moon requires; 235 Lunations will make 6939 Days, 16 Hours, 31 Minutes, and 45 Seconds. Therefore 235 Lunations are not equal to 19 *Julian* Years, but are less by one Hour and an half. And consequently the New Moons after 19 Years, will not return to the same Hour, but will be an Hour and an half sooner; and in 304 Years they will anticipate a whole Day. And therefore the Golden Number will, precisely enough for common use, shew the Lunations in the space of three Centuries, without the Error of one Day. In the Council of *Nice*, when the *Cycle* of the Moon was fitted to the *Kalendar*, and some Centuries afterwards, it did nearly enough give the Time of the New Moons. But the Lunations in every 304 Years, anticipating a whole Day, they now happen almost five Days

Lecture XXIX. ſooner than they ſhould do, according to the Rule of the Golden Number: Notwithſtanding of this, the Church of *England* retains the way of computing the Lunations by the Golden Number, as it was diſpoſed in the Kalendar at the time of the *Nicene* Council: And the New Moons computed in that manner are called Eccleſiaſtical New Moons, to diſtinguiſh them from the true ones, in the Heavens: And the general Table or Rule for finding *Eaſter* for ever, which is in our Liturgy, by the Golden Number and Dominical Letter, is made according to that Diſpoſition of the Golden Number.

IN the firſt Year of the Chriſtian *Æra*, Two was the Golden Number; and therefore if to the current Year of Chriſt we add 1, and divide the Sum by 19, the Remainder after the Quotient, will give the Golden Number.

FROM the *Cycles* of the Sun and Moon multiplied into one another, ariſes a third Period of 532 Years, which is call'd the *Victorian* or *Dionyſian* Period: And after the completion of this Period, not only the New and Full Moons return to the ſame Days of the Month; but alſo the Days of the Months return to the ſame Days of the Week; and therefore the *Dominical* Letters, and the moveable Feaſt's return again in the ſame Order. Hence this *Cycle* is call'd the great *Paſchal Cycle*.

FOR to find the Year of the *Dionyſian* Period for any Year of Chriſt, to the current Year add the Number 457, and divide the Sum by 532, the Remainder after the Quotient, is the Year of the Period.

IT is a *Problem* of another kind: *Having the* Cycles *of the Sun and Moon, to find the Year of the* Dionyſian *Period*. For Example, ſuppoſe the Year of the *Cycle* of the Moon to be 17, and of the Sun 21: For to ſolve this *Problem*, it is requir'd to find a Number, which, when it is divided by 19 leaves 17, and when it is divided by 28 leaves 21. For to find this, let it be requir'd

to

to find two Numbers, one of which will divide exactly by 28, without a Remainder, but when it is divided by 19 leaves 17; and another Number which will divide exactly without a Remainder by 19, but when it is divided by 28 leaves 21: It is plain that the Sum of these two Numbers will answer the Question. Lecture XXIX.

WE will here shew the Analytical Investigation of these two Numbers. We will suppose the first Number to be $28x$, for it is a multiple of 28; and because this Number divided by 19 leaves 17; if we take 17 from it, the Remainder divided by 19 will be a Number; since then 19 divides $28x - 17$, and it also divides $19x$, therefore it will divide their Difference, which is $9x - 17$; consequently $\frac{9x - 17}{19}$ is a Number. Call that Number n, consequently $9x - 17 = 19n$, and $9x = 19n + 17$, and $x = \frac{19n + 17}{9}$ and because x is an intire Number, 9 must divide $19n + 17$, but 9 divides $18n + 9$, therefore it will divide the Remainder $n + 8$, and therefore $\frac{n + 8}{9}$ is a Number. Let that Number be 1, and n will be $= 1$, and $x = 4$; consequently $28x = 112 =$ to the first Number to be found. Suppose the second Number to be $19y$, for it must be a multiple of 19, therefore $\frac{19y - 21}{28}$ is an integer Number; suppose it to be n, than $19y - 21 = 28n$, and $y = \frac{28n + 21}{19}$, which must likewise be an intire Number, and therefore $28n + 21$ will be divided by 19: But 19 divides $19n + 19$, wherefore it will divide the Remainder $9n + 2$, and $\frac{9n + 2}{19}$ is an intire Number: Suppose it $= p$ then is $9n + 2 = 19p$, and $n = \frac{19p - 2}{9}$ there-

Lecture XXIX. therefore 9 must divide $19\,p - 2$; but it divides $18\,p$, therefore it must also divide $p - 2$, and $\frac{p-2}{9}$ is an Integer or o: Let it be equal to o, then is $p = 2$ and $\frac{19p-2}{9} = n = 4$, and $19\,y = 28\,n + 21 = 133$; therefore one of the Numbers is 112, and the other is 133, whose Sum is 245, the Number requir'd: And whenever the *Cycle* of the Sun is 21, and that of the Moon 17, the Year of the *Dionysian* Period is 245.

THE same *Problem* may be otherwise solved, by stated and constant Multiplicators, which are such, that one of them can be divided by 28 without any Remainder, but if it be divided by 19 there remains 1: The other will divide by 19 without a Remainder, but when it is divided by 28 there is a Remainder of 1: Such Numbers are found in the same way as the preceding Numbers were, *viz.* I suppose the first to be $28\,x$, and the other $19\,y$; wherefore 19 will divide the Number $28\,x - 1$, without any Remainder, and therfore it will divide $9\,x - 1$ without a Remainder, and $\frac{9x-1}{19}$ will be a whole Number: Suppose it equal to n, then $x = \frac{19n+1}{9}$, therefore $\frac{n+1}{9}$ is an intire Number, and the least Number that can be put for n is 8: Let therefore $n = 8$, and x being $= \frac{19n+1}{9}$ must be 17, therefore the first Number being $28\,x$, will be 476. Again, let $\frac{19y-1}{28} = n$, then $y = \frac{28n+1}{19}$; suppose $\frac{9n+1}{19} = p$, then is $n = \frac{19p-1}{9}$, and $\frac{p-1}{9}$ is either a whole Number or nothing; let $p - 1 = 0$, and $p = 1$, then $n = \frac{19p-1}{9} = 2$, and $19\,y = 28\,n + 1 = 57$. Therefore the two Numbers that were

were to be found, are 476 and 57. And because the Number 476 divided by 19 leaves 1, if it be multiplied by any Number less than 19, and the Product be divided by 19, there will remain the Number which multiplies it. In like manner, because 57 divided by 28 leaves 1, if 57 be multiplied by any number less than 28, and the Product be divided by 28, there will be left that Number which multiplied 57. Hence we draw this general Rule for finding the Year of the *Dionysian* Period. Multiply the *Cycle* of the Sun by 57, and the *Cycle* of the Moon by 476; divide the Sum of the Products by 532, the Remainder after the Quotient will be the Year of the *Dionysian* Period.

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The Cycle of Indictions.

BESIDES the *Cycles* of the Sun and Moon, there is another Period of Years, which is called the *Cycle* of Indictions, which the *Romans* used, and has no Connection with the Celestial Motions, but is a Revolution of 15 Years, which being compleated, it begins again. It is frequently mentioned in the *Imperial* and *Pontifical Diploma's*. The Year before the Birth of Christ the Indiction was 3, and therefore if to the Year of Christ you add 3, and divide the Sum by 15, the Remainder shews the Year of the Indiction. If there be no Remainder, the Indiction is 15.

The Julian *Period.*

OF these three *Cycles* of the Sun, Moon, and Indiction, by their mutual Multiplication, the *Julian* Period of 7980 Years is composed. This Period had its beginning 764 Years before the Creation; and is not yet compleated, and therefore it comprehends all other *Periods, Cycles* and *Epoches*, and the Times of all memorable Actions and Histories. There is but one Year in the whole Period, which has the same Numbers for the three *Cycles* of which it is made up; and therefore if the Historians had remark'd in their Annals the *Cycles* of each Year, there had been no Dispute about the time of any Action.

From the Year of Christ to find the Julian *Period.*

THE Year before the Birth of Christ was the 4713th Year of the *Julian* Period. And therfore

if

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if to the current Year of Christ we add 4713, the Sum will be the Year of the *Julian* Period: On the contrary, from the Year of the *Julian* Period, substract 4713, there will remain the Year of the Christan *Era*.

From the Cycles *to find the Year of the* Julian *Period.*

Having the Years of the *Cycle* of the Sun, Moon, and Indiction, to find the Year of the *Julian* Period.

This *Problem* may be solved in the same manner as we shew'd in the like Case about the *Dionysian* Period, *viz*, by finding 3 Numbers, such as the first is a Multiple of 19 and 15, or of their Product 285, but being divided by 28, leaves the Number of the *Cycle* of the Sun for a Residue. The second Number must be a Multiple of 28 and 15, or of their Product 420, but being divided by 19 leaves the Year of the *Cycle* of the Moon. *Lastly*, The third must be a Multiple of 28 and 19, but being divided by 15 leaves the Year of the Indiction: The Sum of these Numbers if less than 7980, is the Year of the *Julian* Period. But if the Sum be bigger, divide by 7980, and the Remainder will be the Year of the Period required.

THE *Problem* may likewise be solved by constant and stated Multiplicators, the first of which is a Multiple of the Number 285, but divided by 28 leaves 1. The second is a Multiple of 420, but divided by 19 leaves 1 for a Residue. The third is a Multiple of 532, but being divided by 15 leaves for a Remainder 1. These Numbers are to be found by the same Method we shew'd in our former *Problem*, concerning the *Dionysian* Period, and are 4845, 4200, 6916; which being once found, the Canon or Rule for finding the Year of the *Julian* Period from the Years of the *Cycles*, is this; Multiply the Number 4845 by the Year of the *Cycle* of the Sun, and the Number 4200 by the Year of the *Cycle* of the Moon; likewise the Number 6916 by the Year of the Indiction. Divide the Sum of these Products by 7980, neglecting the Quotient, the Remainder will be the Year of the *Julian* Period required. Example. In the Year 1719, the Year of the *Cycle* of the

Sun

Sun is 19, of the Moon 9, and of the Indiction 11; multiply 4845 by 19, the Product is 92055, and 4200 being multiplied by 9, the Product is 37800; and lastly, 6916 being multiplied by 11, the Product is 76076. The Sum of the Products is 205931, which being divided by 7980, will have a Remainder of 6431 Years, which is the Year of the *Julian* Period. Lecture XXX.

LECTURE XXX.

An Appendix containing a Description and Use of both the Globes; *together with some Spherical* Problems, *that are to be solved by a* Trigonometrical *Calculation.*

OF the Things which pertain to the *Globes*, some are common to both *Globes*, some are peculiar to one of the Two: And those Things that are common are either without the Surface, or painted on the Surface. Without the Surface of the *Globes*, are to be seen.

FIRST, the two *Poles*, about which the *Globes* revolve, the one is the *Arctick* Pole, named so from the two *Bears* that are nigh to it, and is called likewise the *Septentrional* or *North-Pole*, from the *Septem triones*, or the seven Stars of *Charles*'s Wain: The other opposite to it, is called the *Antarctick*-Pole.

SECONDLY, The *Brazen Meridian*, and one side of it only, which is distinguished and divided into Degrees, and which passes through the Poles, represents the true *Meridian*; and this side is always to be turned to the East, and the *North-Pole* to the North. The *Meridian* is divided into four

Lecture XXX. four Quadrants of 90 Degrees, two of which are reckoned from that part of the Equinoctial that is above the Horizon, towards each of the Poles; the other two Quadrants have their Divisions of 90 Degrees, beginning at the Poles and ending in the Equator.

THIRDLY, The wooden Horizon, whose upperside does only represent the Horizon, and is divided into several Circles, the innermost of which contains the twelve Signs of the Zodiack, distinguished by their Names and Characters, and each Sign is divided into 30 Degrees. Next to this is joyn'd two Circles, with the *Julian* and *Gregorian* Kalendars, disposed according to their Months and Days. The outermost is a Circle with all the Points of the Compass, and the Winds as they are denominated by the Seamen.

FOURTHLY, A Brass Quadrant of Altitude, whose Edge is divided into Degrees, and is to be fasten'd to the Meridian at the 90th Degree from the Horizon; from which the Degrees are number'd upon it upwards to the Zenith.

FIFTHLY, The Horary Circle divided into twice twelve Hours: The 12th Hour at Noon is upon the upper part of it, at the Meridian, and the 12th at Night is on the Meridian at the lower side towards the Horizon. The Pole carries round the Hand which shews the Hour, and is in the Center of the Circle: The Hours upon the East-side of the Meridian, are the Morning Hours, these on the West-side are the Hours after noon.

SIXTHLY, The Mariner's Compass is fixed upon the Pediment or Wooden-Frame, which contains the Globe, and by it the Globe is put in a right Position in respect of the Points of the Heavens.

SEVENTHLY, The Semicircle of Position, whose Extremities are fixed to the Points of North and South, so that the Semicircle can be moved freely from the Horizon to the Meridian, and may be raised to any Position. These things we have described

described are without the Globe. But on the Surfaces are delineated the things following. Lecture XXX.

FIRST, The Equinoctial Circle divided into 360 Degrees; the Numbers begin at the Vernal Intersection, or at the first of ♈, and are continued 'till they return to the same.

SECONDLY, The Ecliptick divided into 12 Signs, and each Sign into 30 Degrees, their Names, Characters and Order are to be learned: they are,

♈ *Aries*, or the *Ram*. ♉ *Taurus*, or the *Bull*. ♊ *Gemini*, or the *Twins*. ♋ *Cancer*, or the *Crab*. ♌ *Leo*, the *Lion*. ♍ *Virgo* the *Virgin*. ♎ *Libra* the *Balance*. ♏ *Scorpius* the *Scorpion*. ♐ *Sagittarius* the *Archer*. ♑ *Capricornus* the *Goat*. ♒ *Aquarius* the *Water-bearer*. ♓ *Pisces* the *Fishes*.

THE Sun in his annual Motion passes thro' the Ecliptick, and if we add to it a broad Space of about eight Degrees on each side, we have the Zodiack, in which are the 12 *Asterisms* or Constellations, the most of which have the likeness of some living Creature; upon which Account the Zodiack has its Name. In this broad Circle the Moon and all the Planets perform their Motions: The Ecliptick is to be distinguished from the Equinoctial Circle by this, that the Equinoctial, while the *Globe* is turned, does always cut the Meridian and the Horizon in the same Points. But the Ecliptick constantly changes its Position; sometimes while the *Globe* is turning it is high, sometimes it is low, sometimes it cuts the Equator and the Horizon in one Degree, sometimes in another.

THIRDLY, There are the two Tropicks of ♋ and ♑, which are the Limits or Boundaries of the Sun's Deviations from the Equinoctial, either towards North or South, including between them the

the Oblique Courſe of the Sun, that is the Ecliptick, and may be called the outermoſt of the Sun's Parallels. For becauſe the Sun every Day paſſes to a different Degree of the Ecliptick in its Annual Motion, that Degree with the Sun in it, being carried round the Earth by the Diurnal Revolution of the Heavens, will deſcribe a Circle Parallel to the Equator, and then there muſt be ſo many Parallels, as there are Days from the longeſt to the ſhorteſt; tho' the Sun does not remain for a Day in one Point of the Ecliptick, but is continually advancing forward; and therefore does not deſcribe a perfect Parallel, but rather a Spiral Line: But the Diſtance between each Spire being but very ſmall, eſpecially near the Tropicks, we may well ſuppoſe the ſingle Revolutions, but eſpecially the outermoſt, to be Parallels; which is ſufficient for common Uſe, and is moſt convenient.

FOURTHLY, The two Polar Circles the Arctick and Antarctick, which have been explained in our VII and XVIII *Lecture*. Theſe things we have here mention'd, are common to both *Globes*, tho' the Ecliptick and the Semicircle of Poſition, do properly belong only to the Celeſtial *Globe*; yet they are put upon the Terreſtrial *Globe* alſo, that the Phænomena which depend upon the Motion of the Sun and the Points or Cuſps of the Houſes, may be thereby explain'd, if needful.

THOSE things which are peculiar or proper to one ſort of *Globe*, are Partly ſome Circles or Curve Lines, as in the Celeſtial *Globe*, the two *Colures*, and the *Circles* of *Latitude*. In the Terreſtrial the Meridian's, Parallels and Rumbs: Partly the Repreſentations in the Terreſtrial *Globe*, of Seas, Iſlands and Countries, which we leave to the Geographers to deſcribe. In the Celeſtial *Globe* the Figures of the Conſtellations are painted, and the Stars repreſented in the ſame Order, Magnitude and Poſition, they have in the Heavens. Theſe we have enumerated in our VII *Lecture*.

HAVING described the *Globes*, we come now to shew their Use, which is manifold; but for our present Purpose, it is chiefly contained in the following *Problems*. Lecture XXX.

PROBLEM I. *Having a place in the Terrestrial* Globe, *to find its Longitude and Latitude.*

Turn the *Globe* 'till the Place comes to the Meridian (I mean to the Eastern side of the Brass Meridian) and the Degree of the Equator which is then under the Meridian, whatever Number it is mark'd by, shews the Longitude of the Place; then upon the Meridian count up from the Equator the Degrees mark'd, 'till you come to the Place, and you have the Latitude, which will be North Latitude, if the Place be on the North side; or Southern, if it lies upon the Southern side of the Equator.

PROBLEM II. *Having the Longitude and Latitude, to find out the Place on the Terrestrial* Globe *to which they belong*: Seek in the Equator the Degree of Longitude that is given, and bring it to the Meridian; then count from the Equator on the Meridian the Degree of Latitude given, towards the Arctick or Antarctick Pole, according as the Latitude is either North or South, and under that Degree of Latitude lies the Place, that was to be found.

PROBLEM III. *To rectify both* Globes, *and set them to a given Latitude or Elevation of the Pole; and to apply the Quadrant of Altitude to the Vertical Point; and to place the* Globes *according to the Points of the Compass, by Help of the Needle.* If the Latitude of the Place be North, raise the Arctick Pole above the Horizon; But for a South Latitude, you must raise the Antarctick: Then from the elevated Pole, count upon the Meridian towards the Horizon, the Degrees of the Poles Elevation; and that Point where the Reckoning ends, bring to the Horizon, and then the *Globe* is adjusted to a due Elevation. Count from the Equator on the Meridian the Latitude required, and there will be the Vertex of the Place, or the Zenith.

 To

Lecture XXX. To this Point of the Meridian faften the Quadrant of Altitude, with the Screw which is at the end of it, fo that the Edge of the Quadrant which is divided into Degrees may be join'd to this Point. *Laftly*, Turn the whole Frame in which the *Globe* is with its Pediment, 'till the Magnetick Needle lie in the Plane of the Meridian, fo that the North Point of the Horizon of the *Globe* be turn'd Northwards; then will the reft of the Points on the Horizon of the *Globe* agree with the correfponding Points of the Horizon of the Place.

PROBLEM IV. *To find for any Day of the Year the Degree or Place of the Sun in the Ecliptick, by the Help of the Kalendar, and the Circle of Signs adjoin'd; and then to mark it upon the Ecliptick.* Seek in the wooden Horizon, the Month and Day given, but take care to diftinguifh the *Julian* and *Gregorian* Kalendars, that you may not miftake the one for the other: Then in the innermoft Circle, which is the Circle of Signs, over-againft the Day, you will fee the Degree and Sign in which the Sun is that Day. In the Ecliptick which is drawn upon the Surface of the *Globe*, feek firft the Sign, and then the Degree of the Sun's Place. The place of the Sun is more accurately found out by an *Ephemeris*, which is made for each Year, or elfe it may be calculated by *Aftronomical* Tables.

PROBLEM V. *To find the right Afcenfion and Declination of the Sun, or any Star; and by that means to adjuft the Hand which points the Hours to the twelfth Hour.* Bring the Sun's Place in the Ecliptick, found by the laft *Problem*, to the Meridian, and mark the Degree of the Equator which is then under the Meridian, that will be the right Afcenfion of the Sun: Then compute from the Equinoctial on the Meridian, the Number of Degrees to the Place of the Sun, they will fhew the Sun's Declination, which will either be North or South, as the Sun is on this or the other fide of the Equator. When the Place of the Sun is in the Meridian, turn the Hour-hand upwards 'till it comes to the twelfth Hour at Noon. After the

fame

ſame manner bring the Place of any fixed Star to the Meridian, and you ſhall find its right Aſcenſion on the Equator, and its Declination on the Meridian. Having the Place of the Sun, we ſhew'd how to find its right Aſcenſion and Declination by *Trigonometry* in our XIX *Lecture*. Lecture XXX.

PROBLEM VI. *To find the Meridian Altitude of the Sun, or any fixed Star by a Quadrant, or any other Inſtrument fit for the Purpoſe.* We ſhew'd the Method of obſerving the Sun's or a Star's Altitude in *Lecture* XIX.

PROBLEM VII. *Having the Declination and Meridian Altitude of the Sun, or of a fixed Star, to find the Latitude of the Place or Height of the Pole above the Horizon.* The Method of finding the Latitude by Obſervation was likewiſe explain'd in *Lecture* XIX.

PROBLEM VIII. *Having the right Aſcenſion of the Sun and of a fixed Star: To find the Time when the Star culminates or comes to the Meridian.*

Subſtract the right Aſcenſion of the Sun from the right Aſcenſion of the Star, adding, if needful, 360 Degrees; and there will remain the Arch of the Equator that has paſſed the Meridian between Noon and the time of the Culmination: turn this Arch into Time, by dividing the Degrees by 15, and the Quotient gives the Hours; then multiply the remaining Degrees by 4, and you have the Minutes; and likewiſe divide the Minutes, which are the Parts of Degrees, by 15, and the Quotient gives the Horary Minutes: And if there be any Minutes of Degrees remaining after the Diviſion, multiply them by 4, and you have the Horary Seconds: The time made up of theſe Hours, Minutes and Seconds ſhews the Moment of the Culmination of the Star.

PROBLEM IX. *Having the Place of the Sun, or any Star, to find its Oblique Aſcenſion and Deſcenſion; as alſo its Eaſtern and Weſtern Amplitude.* Bring the Place of the Sun or Star to the Horizon in the East, and mark the Point of the Equator that riſeth with it; it will be its Oblique Aſcenſion: then count from the Point of Eaſt up-

Lecture XXX. on the Horizon, to the Place of the Sun or Star; the Degrees intercepted will be the Eaſtern Amplitude. If you bring the Place of the Sun or Star to the Weſtern ſide of the Horizon, the Degree of the Equator which goes down with it, is the Oblique Deſcenſion; and the Arch of the Horizon between the Weſt Point and the Place of the Sun or Star, is the Weſtern Amplitude.

THE *Trigonometrical* Solution of the *Problem* is this: Let H P O P be the Meridian Æ Q the Equator, P the Pole, S the Sun, or Star in the Horizon, whoſe Declination is S R; *or* the Point of Eaſt or Weſt. In the right-angled Triangle *or* R S, we have the ſide R S the Declination of the Sun or Star, and the Angle R *or* S, which the Equator makes with the Horizon, and is equal to the Complement of the Latitude; whence we ſhall find the Arch *or* R, which is the Aſcenſional Difference of the Sun or Star; which, added to the right Aſcenſion, or ſubſtracted from it, according as the Sun or Star is towards the depreſſed or elevated Pole, gives the oblique Aſcenſion. We ſhall have moreover in the ſame Triangle, the Arch *or* S, the Amplitude of the Sun or Star. The Aſcenſional Difference added to a Quadrant, or ſubſtracted from it, according as the Sun or Star is towards the elevated or depreſſed Pole, gives the Semidiurnal Arch; which being turned into Time, ſhews the Time of half the Stay of the Sun or Star above the Horizon.

TableXXVI Fig. 3.

PROBLEM X. *Having the Aſcenſions of the Sun or Star, both Right and Oblique, to find the half Time of their Stay above the Horizon: As alſo the Length of Day and Night, and the Time of Sun-riſing and ſetting.* Take the Difference of the Oblique and Right Aſcenſion, and we ſhall have the Aſcenſional Difference: convert it into Time, as we ſhew'd in the VIIIth *Problem*, which, when the Sun or Star declines to the elevated Pole, is to be added to ſix Hours; but if to the depreſſed *Pole*, it is to be ſubſtracted from ſix Hours; and we ſhall have half the Time of the Stay of the Sun or Star

above the Horizon: and its Complement to 12 Hours, is half the Time it abides under the Horizon: Half the Time of the Sun's Stay above the Horizon, being computed from Noon, gives the Time of Sun setting; and half the time of the Sun's Stay under the Horizon computed from Midnight, gives the Hour of the Sun's rising; and the half Time of the Sun's Stay above the Horizon being doubled, gives the Length of the Day; and the half Time of the Stay below the Horizon doubled, gives the Length of the Night. If you put the Hour-hand to the 12th Hour, when the Place of the Sun is in the Meridian, and turn the *Globe* round, 'till the Place of the Sun comes to the Eastern side of the Horizon, the Hand will point out the Hour of Sun-rising: Bring it to the Western side of the Horizon, and the Hand will shew the Time of Sun-setting; from which it is easy to compute the Length of Day and Night. Lecture XXX.

PROBLEM XI. *Having the Time of the Culmination of a Star, and of its half Stay above the Horizon; To find the Hour of its rising and setting.* If from the Time of the Star's Culmination, you substract the Time of the half Stay above the Horizon, you will have the Hour wherein the Star riseth: If you add that Time to the Time of the Culmination, you shall have the Time of the Star's setting, which in both Cases is computed from Mid-Day. Or, if when the Place of the Sun culminates, you bring the Hour-Hand to the twelfth Hour, and then turn round the *Globe*, 'till the Star comes to the Eastern or Western side of the Horizon, the Hand will point to the Hour of the rising or setting of the Star.

PROBLEM XII. *To find the Degree of the Ecliptick, which rises or sets with a given Star; and from thence to determine its Cosmical and Acronycal rising and setting.* Bring the given Star to the Eastern or Western side of the Horizon, and mark what Degree of the Ecliptick rises or sets with it; then in the wooden Horizon look for that Sign and Degree which rose or set with the Star, and over-

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over-againſt it in the Kalendar, you will find the Month and Day of the Coſmical riſing of the Star. And if you look in the ſame Horizon the Point oppoſite to the riſing Point; over-againſt it in the Kalendar you ſhall have the Month and Day of its Coſmical ſetting. So likewiſe over-againſt the Degree that ſets with the Star, you will find the Day and Month of the Acronycal ſetting, and the oppoſite Degree will ſhew in the Kalendar the Day and Month of the Star's Acronycal riſing.

Table XXVI Fig. 3.

THE *Trigonometrical* Solution of the *Problem* is this: Let H O be the Horizon, H Z O the Meridian, ÆQ the Equator, E C the Ecliptick. ♈ the Point of Interſection of the Equator and Ecliptick; A the Point of the Ecliptick which riſes with the Star, and the Point of the Equator which riſes with the Star, ſuppoſe to be *or*. In the Triangle ♈ *or* A, we have ♈ *or* the oblique Aſcenſion of the Star; and the Angle ♈ the Inclination of the Equator and Ecliptick; and the Angle ♈ *or* A, the height of the Equator above the Horizon, or its Complement to two right Angles. Hence we ſhall find the Arch of the Ecliptick ♈ A, and the Point of it A which riſes with the Star. But by the Kalendar, or an *Ephemeris*, we have the Time when the Sun is in that Point; and therefore we have the Time when the Star riſes Coſmically; we have likewiſe the Angle ♈ A, or the Angle of the Ecliptick and the Horizon at the riſing Point. When the Sun is in the Point oppoſite to the Point A, then the Star riſes Acronycally: And by a like Calculation, we ſhall find the Time the Star ſets Coſmically or Achronycally.

PROBLEM XIII. *Having the Latitude of the Place and the Degree of the Ecliptick which riſes or ſets with the Star; to determine the Heliacal riſing or ſetting of a Star.* Bring the Star to the Eaſtern ſide of the Horizon, and turn the Quadrant of Altitude round to the Weſtern ſide, 'till it cut the Ecliptick in the twelfth Degree from the Horizon, on the Quadrant of Altitude, if the Star be of the firſt Magnitude. Then mark the Point of the

Ecliptick

Ecliptick where the Quadrant interſects it; that Point when the Star riſes is twelve Degrees high above the Weſtern Horizon, but at the ſame Time the oppoſite Point is twelve Degrees below the Eaſtern Horizon: Look that Point in the Wooden Horizon, and over-againſt it, you will find the Month and Day when the Sun enters that Point of the Ecliptick; which is the Day of the Star's riſing Heliacally; when it begins to get ſo far from the Sun's Beams, that it may be ſeen in the Morning before Sun-riſing. But if you would know the Heliacal ſetting: Bring the Star to the Weſt ſide of the Horizon, and turn the Quadrant of Altitude to the Eaſt ſide, 'till the 12th Degree of it from the Horizon cuts the Ecliptick, and mark that Point where it interſects the Ecliptick; the Point oppoſite to this is ſo many Degrees depreſs'd under the Horizon at the Weſtern ſide; and if we find, in the Wooden Horizon, the Month and Day when the Sun comes to that Point, we ſhall have the Time of the Heliacal ſetting.

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By *Trigonometry* the *Problem* is thus to be ſolved: In the Figure of the preceding *Problem*, let A be the Point of the Ecliptick, which riſes with the Star: And ſuppoſe the Sun in the Ecliptick at ☉, ſo that the Arch ☉ R of the Circle of Depreſſion may be 12 or 13 Degrees, according as the Star is of the firſt or ſecond Magnitude. In the right angled Triangle A R ☉, we have the Angle R A ☉ the Angle of the Ecliptick and Horizon, and the ſide R ☉, which is 12 or 13 Degrees: Hence we ſhall have the ſide A ☉, which added to ♈ A gives the Arch ♈ ☉, and the Point ☉, which the Sun muſt be in when the Star riſes Heliacaly. In the ſame manner we may find the Time of the Heliacal ſetting. Table XXVI. Fig. 3.

PROBLEM XIV. *Having the Latitude of the Place, and the Place of the Sun in the Ecliptick; To find the beginning and end of Twy-Light.* Rectify the *Globe* for the Latitude of the Place by *Problem* third, and put the Hour-hand to the twelfth Hour, the Sun's Place being in the Meridian; then

Lecture XXX. then take the Point of the Ecliptick oppoſite to the Sun's Place, and turn the *Globe* Weſtward, as alſo the Quadrant of Altitude, 'till the Point oppoſite to the Sun's Place cut the Quadrant of Altitude in the 18th Degree above the Horizon: The Hour-hand will ſhew the Time of Dawning in the Morning. But if you take the Point oppoſite to the Sun, and bring it to the Eaſtern Hemiſphere, and turn it 'till it meets with the Quadrant of Altitude in the 18*th* Degree, the Hand will ſhew the Hour when Twylight ends in the Evening. The *Trigonometrical* Solution of this *Problem* is in *Lecture* XX.

PROBLEM XV. *Having the Latitude of the Place, and the Place of the Sun, if we have beſides any one of the three following things,* viz. *The Hour of the Day or Night; or the Altitude or Azimuth of the Sun or a Star: To find the other two.* Rectify the *Globe* for the Latitude given, and bring the place of the Sun to the Meridian; and the Hour-hand to the Twelve a Clock Hour: Then if the Hour be given, turn round the *Globe* 'till the Hand points to it, and bring the Quadrant of Altitude to the place of the Sun or Star; you will ſee in the graduated Edge, the Degree of Altitude; and where the Quadrant interſects the Horizon, there you will find its Azimuth, to be counted from the Interſection of the Meridian and Horizon: But if the Altitude be given, turn the *Globe* with one Hand, and the Quadrant of Altitude with the other, 'till the place of the Sun meet with the Quadrant at the given Altitude; then the Hand will point to the Hour; and the Interſection of the Quadrant and Horizon will ſhew the Azimuth. But if the Azimuth be given, turn the Quadrant 'till it interſects the Horizon at the given Azimuth, and there keep it fixed; but turn the *Globe* 'till the place of the Sun or Star meets with the Quadrant, and the Degrees upon the Quadrant to the place of the Sun or Star, from the Horizon, will give the Altitude; and the Hour Hand will point to the Hour.

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THE *Problem* is solved *Trigonometricaly* thus, Let H O be the Horizon, H P O the Meridian, Æ Q the Equator, Z the Vertex or Zenith, P the Pole, S the Sun or Star, whose distance from the Vertex is Z S, and S P the Complement of Declination, or its distance from the Pole. Because we have the Right Ascensions of the Sun and Star, we have the difference of their Right Ascensions, which being turned into Time, will shew the Time of the Culmination of the Star; and the Arch which measures the Angle Æ P S, being turned into Time, will give the Hour of the Night. Now in the Triangle Z P S, having Z P the distance of the Zenith from the Pole, and PS the Complement of the Declination of the Star; if I have besides these two the Angle P, which the Hour gives, we can from them find the Angle Z, which shews the Stars Azimuth, and the Arch Z S the Stars Zenith distance, which will shew the Altitude. Or if we have the Arch ZS, we shall find the Angle P, and by that the Hour of the Night; as also the Angle P Z S the Azimuth. Or if we have the Angle P Z S, we can from thence find Z S the Complement of the Altitude, and the Angle Z P S, which will give the Hour. By the same method having the Altitude of the Sun, which we take by an Observation, and his Declination, which is known by Tables from his place in the Eclipticк, we can find the Angle Æ P S, which being turned into Time, will give the Hour of the Day. Lecture XXX. Table XXV Fig. 4.

PROBLEM XVI. *To find the distance between two places on the Surface of the Terrestial Globe.*

Let us for distinction sake, call one of the places the first, and the other the second. Rectify the *Globe* for the Latitude of the first place, and bring it to the Meridian, and there fix the *Globe* with the Quadrant of Altitude to the Vertex, and turn the Quadrant 'till its graduated Edge pass thro' the second place: Then count the Degrees of distance from the Vertex to the second place,

Lecture XXX. place: And the Arch of the Horizon intercepted between the Meridian and Quadrant will give you the Angle of Position.

Table XXVI Fig. 5. BY *Trigonometry* we thus proceed. Let ÆQ be the Equator, P the Pole, S, *s* two places, whose Complements of Latitude are PS and P*s*; and because their Longitudes are given, we have their difference of Longitude, which is measured by we Angle SP*s*: therefore in the Triangle SP*s*, the have the sides SP, *s*P, with the Angle SP*s*: by them we can find S*s* in Degrees and Minutes, which being converted into Miles, allowing 69 English Miles for each Degree, we shall have their distance in Miles. We can also find the Angles PS*s* and P*s*S, which are the Angles of Position.

IN the same manner in the Heavens, if we have the Right Ascensions and Declinations of two Stars, or their Longitudes and Latitudes, we shall find their distances.

PROBLEM XVII. *For any Time and place, to erect the Theme or Scheme of the Heavens.* Rectify the Celestial *Globe* for the Latitude of the Place. If you have not a Celestial *Globe*, a Terrestial will do. Take the place of the Sun for the given Time, and bring it to the Meridian, and the Hour-hand to the Twelfth Hour; then turn the *Globe* 'till the Hand shews the given Hour: Or if you like to be more accurate in your Work, to the Right Ascension of the Sun add so many Degrees and Minutes, as the Time from Mid-day requires, for every Hour counting 15 Degrees, and for every four Minutes a Degree, rejecting, if it exceeds it, 360 Degrees; so by this you will have the Right Ascension of Mid-heaven, or the Degree of the Equinoctial which then Culminates, which is to be placed under the Meridian. Then fasten the Semicircle of Position to the Meridian, at the Points of South and North

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in the Horizon. From the Point of the Equator culminating, count on the Equator 30 Degrees Eastward, and bring the Semicircle of Position to the 30th Degree, and observe in what Degree this Semicircle cuts the Ecliptick; that will be the Cusp of the Eleventh House, which must be set down on Paper. Again, move the Semicircle of Position to the 60th Degree of the Equinoctial from the culminating Point, and mark where it cuts the Ecliptick, and you have the Cusp of the Twelfth House, which is likewise to be writ down. Bring the Semicircle of Position to the Western side, and count 30 Degrees from the culminating Point, and letting the Semicircle pass thro' that Point, observe where the Semicircle cuts the Ecliptick; that will be the Cusp of the 9th House. Then count from the Culminating Point again Westward 60 Degrees, and the Semicircle of Position passing thro' that Point will cut the Ecliptick in the Cusp of the 8th House: and the Meridian cuts the Ecliptick in the Cusp of the Tenth House. And the place where the Horizon Eastward cuts the Ecliptick, is the Cusp of the First House or the *Horoscope*; And the Western side of the Horizon shews in the same Ecliptick, where it cuts it, the Cusp of the Seventh House: and as it is Diametricaly opposite to the First; so is the Second to the Eighth; and the Third to the Ninth; the Fifth to the Eleventh; and the Sixth to the Twelfth.

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PROBLEM XVIII. *Having erected the Theme to direct any Point to any other Point.* To a Planet or Aspect assign its place in the Zodiack, according to its Longitude and Latitude; and chuse any Planet or Degree of the Ecliptick, which you would direct, and which, for distinction sake, we will call the first Place; and the Place to which you would direct this first Place, call the second: Then thro' the first Place, which used to be called the Significator, draw the Semicircle of Position, and mark that Degree in which

it cuts the Equator; then keeping the Semicircle in the ſame Poſition, turn the Globe Weſtward, 'till the ſecond Place arrive at it; and then again obſerve where the Equinoctial is cut by the ſaid Semicircle. Subſtract the Degree firſt obſerved, from the Degree obſerved in the ſecond; adding, if need be, 360 Degrees; the remainder is the Arch of Direction, which was to be found.

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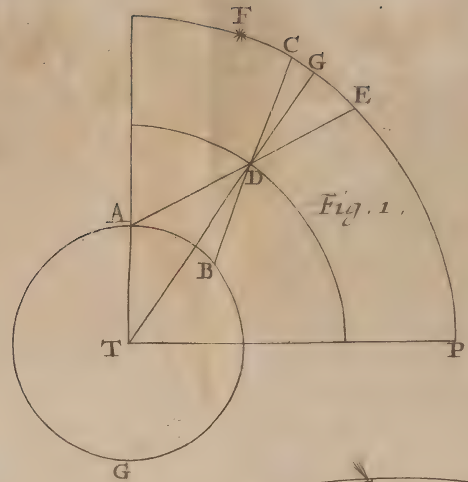
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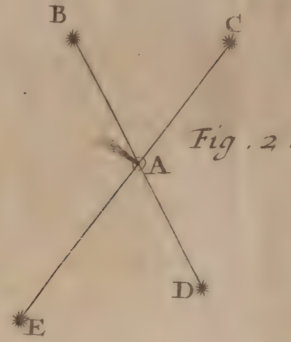
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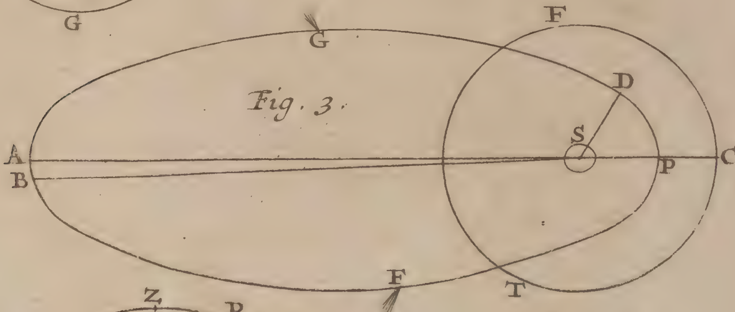
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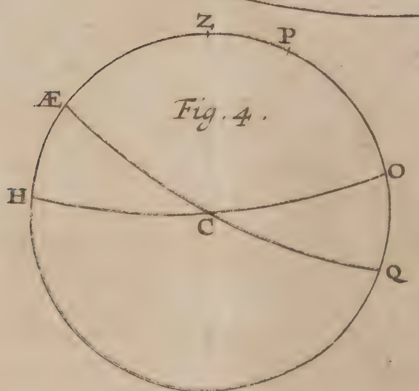
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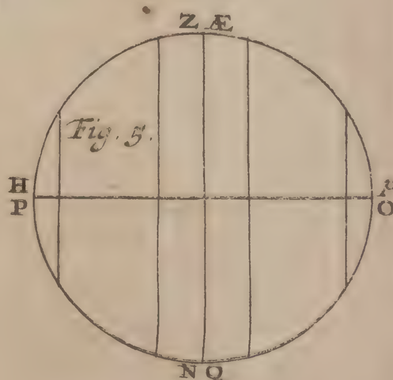
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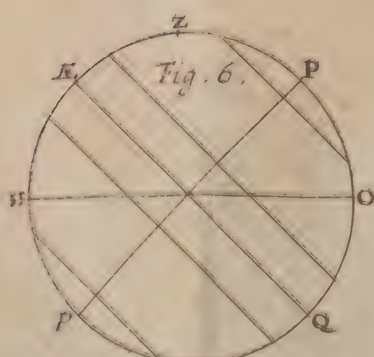
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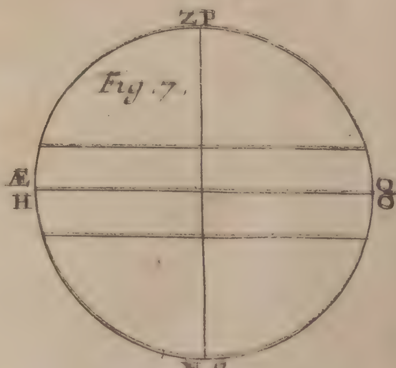
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